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Laboratory Evaluation of the Cleanable High Efficiency Air Filter (CHEAF)

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16. ABSTRACT The report gives results of testing a novel scrubber, the Cleanable High Efficiency Air Filter (CHEAF), as part of a program to identify novel high efficiency fine particle control devices. The scrubber was tested at room temperature, using iron oxide aerosols of concentrations near 0.2 g/cu m (0.1 grain/cu ft), mass median aerodynamic diameter of 1.1 micrometers. Inlet and outlet samples were taken with cascade impactors, total mass filters, a condensation nuclei counter, and an optical particle counter. These tests were performed with different filter media, at different face velocities, and at different water spray rates and water recycle rates. Efficiency increased with increases in: foam pores per inch, pressure drop, flow rate, spray rate, and make-up water addition. The results were consistent with the hypothesis that impaction is the major collection mechanism and re-entrainment contributes substantially to penetration. Total mass efficiency was approximately 95 percent at normal conditions, for which the pressure drop across the CHEAF was 80 cm (31.5 inches) WC. The particle aerodynamic cut diameter, for which the efficiency would be 50 percent at these conditions, was determined from cascade impactor data to be below 0.5 μm. This indicates that the 50 percent cut diameter for the CHEAF is smaller than for a venturi scrubber operating at the same pressure drop.

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EPA-600/2-76-202
July 1976

LABORATORY EVALUATION OF THE CLEANABLE HIGH EFFICIENCY AIR FILTER (CHEAF)

by

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ABSTRACT

A novel scrubber, the CHEAF (Andersen 2000, Atlanta, Georgia) was tested as part of a program to identify novel high efficiency fine particle control devices. The tests were performed at room temperature using iron oxide aerosols of concentrations near 0.2 g/m^3 (0.1 $grain/ft^3$), mass median aerodynamic diameter of 1.1 μm. Inlet and outlet samples were taken with cascade impactors, total mass filters, a condensation nuclei counter, and an optical particle counter. These tests were performed with different filter media, at different face velocities, and at different water spray rates and water recycle rates. Efficiency increased with increases in: foam pores per inch, pressure drop, flow rate, spray rate, make-up water addition. The results were consistent with the hypothesis that impaction was the major collection mechanism and re-entrainment a substantial contributor to penetration. Total mass efficiency was approximately 95 percent at normal conditions, for which the pressure drop across the CHEAF was 80 cm (31.5 inches) WC. The particle aerodynamic cut diameter, for which the efficiency would be 50 percent at these conditions, was determined from cascade impactor data to be below 0.5 μm. This indicates that the 50 percent cut diameter for the CHEAF is smaller than for a venturi scrubber operating at the same pressure drop.

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SECTION I

CONCLUSIONS

This evaluation was one of a series of such evaluations being conducted by the Control Systems Laboratory of the Environmental Protection Agency to identify and test novel devices which are capable of high efficiency collection of fine particles. The overall efficiency of the CHEAF was improved by increasing the spray rate, the make-up liquid rate, the foam pores per inch, the pressure drop and/or the face velocity at the filter drum. Face velocity was not as important as pressure drop, however, when various filter media were compared. The mean efficiencies and estimated standard deviations of these means are listed below (for tests near normal operating conditions, as specified by the manufacturer):

Aerodynamic diameter, μm	Mean efficiency, %	Estimated standard deviation of the mean, %
9	90.8	1.9
7	93.5	1.6
5	93.4	1.2
3	97.4	0.5
1	97.1	0.4
0.5	90.4	2.8

The penetration actually increased as particle size increased, which is the opposite behavior expected from theory and found in normal practice. This effect appears to be due to reentrainment and possibly leakage around seals which may not perform as well in the small pilot scale unit as in a full scale industrial unit. The major collection mechanism was impaction and the major penetration mechanism was probably reentrainment, for the aerosol studied. Total mass efficiency was approximately 95 percent at normal conditions, for which the pressure drop across the CHEAF was 80 cm (31.5 inches) WC. The particle aerodynamic diameter, for which the efficiency would be 50 percent at these conditions, was determined from cascade impactor data to be below 0.5 m. This indicates that the aerodynamic 50 percent cut diameter for the CHEAF is smaller than for a venturi scrubber operating at the same pressure drop.

SECTION II

RECOMMENDATIONS

For operations for which scrubbers are practical, the CHEAF system should be considered as an alternative which may represent a savings in power consumption at equivalent collection efficiency.

SECTION III

INTRODUCTION

The CHEAF is a particulate control device which utilizes a wetted polymer foam material to capture particulate matter. The water acts as an aid in particulate collection at the foam, and as a continuous cleaning agent. A more complete description of the CHEAF by the manufacturer (Andersen 2000, Inc.) is given in Appendix A.

The goals of the CHEAF evaluation were to determine its fractional and overall efficiency, its power and water consumption, and the relative importance of different collection mechanisms. A balanced factorial test matrix was designed utilizing three levels of foam pore grade (pores per inch) and three levels of face velocity. At the normal operating conditions (labeled 3222 in Table 1 for the third level of face velocity, and the second levels of pore grade, spray flow, and make-up flow, respectively), four tests were made with impactors, two tests with total mass filters at the duct center-line, two tests with total mass filters taken at traverse points called for in EPA Method 5,[1] one test with the optical particle counter, and one test with the condensation nuclei counter. The three extreme conditions of pore grade and face velocity (1122, 3122, 1322) were each tested with one run using impactors, total mass filters, an optical particle counter and a condensation nuclei counter. The two remaining runs in the matrix which were run at the second level of face velocity with the extremes of pore grade (2122, 2322) were tested with one run each using impactors and total mass filters.

Table 1. TEST PROGRAM FOR CHEAF EVALUATION

Principal test matrix

Face velocity	Foam pores per inch		
	45 ppi	65 ppi	80 ppi
250 cm/s (500 fpm)	1122[b]	1222[b]	1322[b]
500-600 cm/s (1000-1200 fpm)	2122	2222	2322
1000 cm/s (2000 fpm)	3122[b]	3222[a,b]	

Secondary test series

Spray/gas, gpm/1000 cfm	Test number
1.5	3212[d]
1.1	3222[c]

Make-up/gas, gpm/1000 cfm	Equivalent volume fraction, %	Test number
0.03	1	3221[d]
0.10	0.3	3222[c]
0.30	0.1	3223[d]

---

[a] Four total mass tests: two EPA Method 5; two in-stack filter.

[b] Tests with condensation nuclei counter, diffusion battery, and optical particle counter, in addition to impactors and filters.

[c] Tests already done for principal matrix.

[d] Two tests each.

Secondary conditions were chosen to include two water spray rates and three solids loadings in the recirculation water. The use of different solids loadings simulated operating at different bleed and make-up flow rates. In this manner we can determine actual water consumption, exclusive of recirculation rates. Two impactor and total mass tests were made at each of the three water use rates (3212, 3221, 3223) which were different than nominal conditions. Table 1 displays the test matrix and conditions we intended to utilize for the tests which were performed. Table 2 contains the actual values used for the tests.

Table 2. ACTUAL VALUE OF PARAMETERS IN TEST MATRIX

Run no.	Foam type pores per inch	Water solids content, % by volume	Face velocity, cm/s	Liquid-to-gas ratio, $10^{-3} m^3/m^3$
3222 series	65	0.3	797	0.19
3212 pair	65	0.3	759	0.26
3221 pair	65	1.0	680	0.21
3223 pair	65	0.1	733	0.23
2222	65	0.3	530	0.18
1222	65	0.3	243	0.39
3122	45	0.3	840	0.18
2122	45	0.3	548	0.18
1122	45	0.3	262	0.37
2322	80	0.3	331	0.29
1322	80	0.3	361	0.27

The face velocity was determined by dividing the exposed area of the polymer filter into the total gas flow through the filter. The liquid-to-gas ratio was determined by dividing the water spray rate through the nozzles by the gas volume flow rate at the foam.

Tests were also performed using a metal foam of approximately 60 pores per inch to determine the overall and fractional penetration of the CHEAF utilizing this foam at otherwise nominal conditions.

SECTION IV

TEST EQUIPMENT AND PROCEDURE

EXPERIMENTAL SET-UP

The general schematic of the test system for the CHEAF evaluation is shown in Figure 1. The iron oxide aerosol output from a screw-type dust feeder was aspirated into the inlet of the test ducting where it mixed with room air. (The Reynolds number at 0.5 m^3/s (10^3 cfm) was 2 x 10^5, and earlier work with a similar set-up indicated good mixing under these conditions.) The ducting diameter was 20 cm (8 inches). There were more than 8 diameters of duct length before the sampling probes, and about 2 after the probe before a right-angle bend. The CHEAF unit has a cyclone with a spray preceding the wetted foam part of the unit. After the wetted foam are two types of demisters and a blower (still part of the CHEAF), followed by more ducting with a sampling configuration which was nearly identical with the upstream configuration.

The sampling equipment was arranged as shown in Figure 2, with long straight probes placed in the elbows of the inlet and outlet ducting. The reason for using the straight sampling probe was to minimize probe losses which normally occur when utilizing impactors with the standard button hook type nozzles. This avoided probe bends and yet allowed sampling at least two diameters upstream from the duct bend. The sample was pulled isokinetically through the nozzle, then through the probe, to the filter holder or Andersen Mark III impactor, followed by a column of dessicant

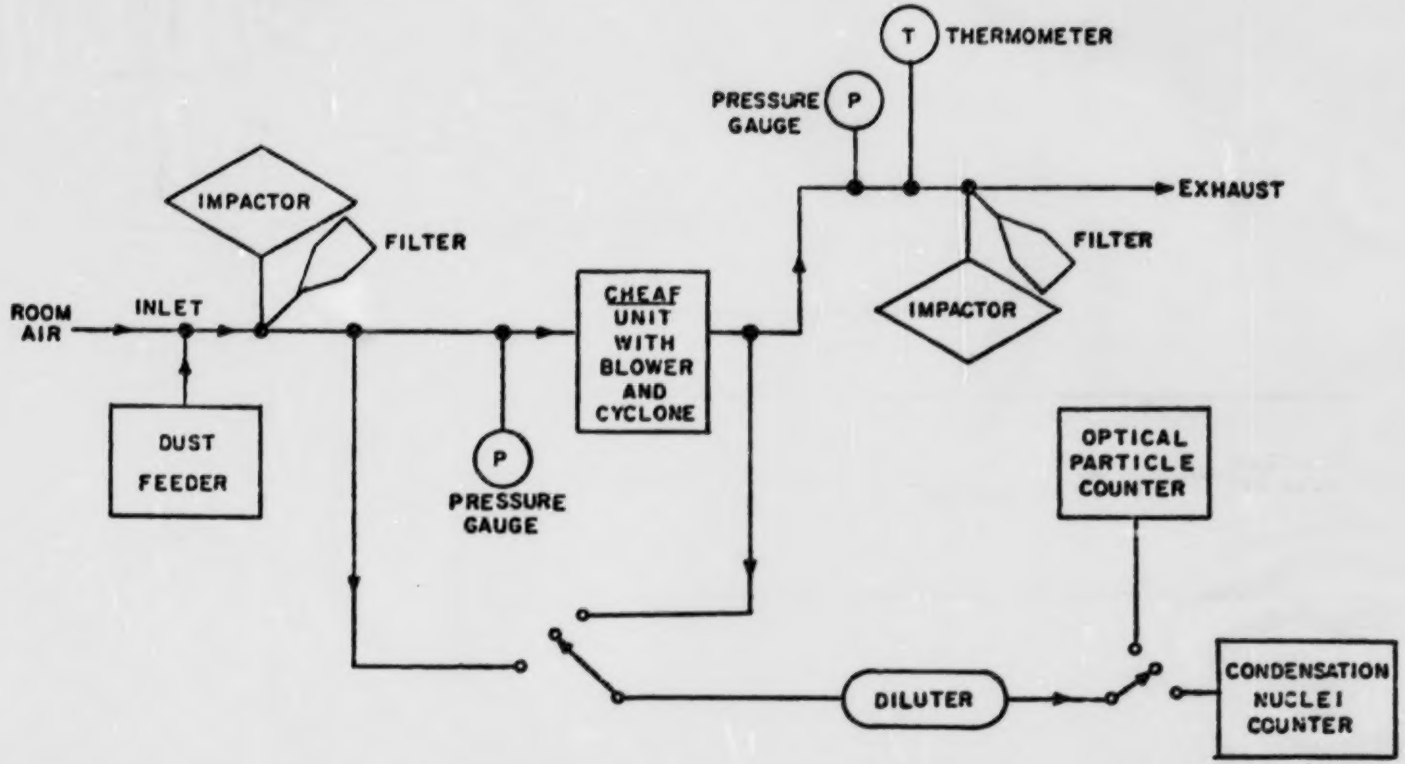
ROOM AIR
INLET
IMPACTOR
FILTER
DUST FEEDER
P
PRESSURE GAUGE
CHEAF UNIT WITH BLOWER AND CYCLONE
PRESSURE GAUGE
P
T
THERMOMETER
EXHAUST
FILTER
IMPACTOR
OPTICAL PARTICLE COUNTER
DILUTER
CONDENSATION NUCLEI COUNTER

Figure 1. Test system for CHEAF evaluation

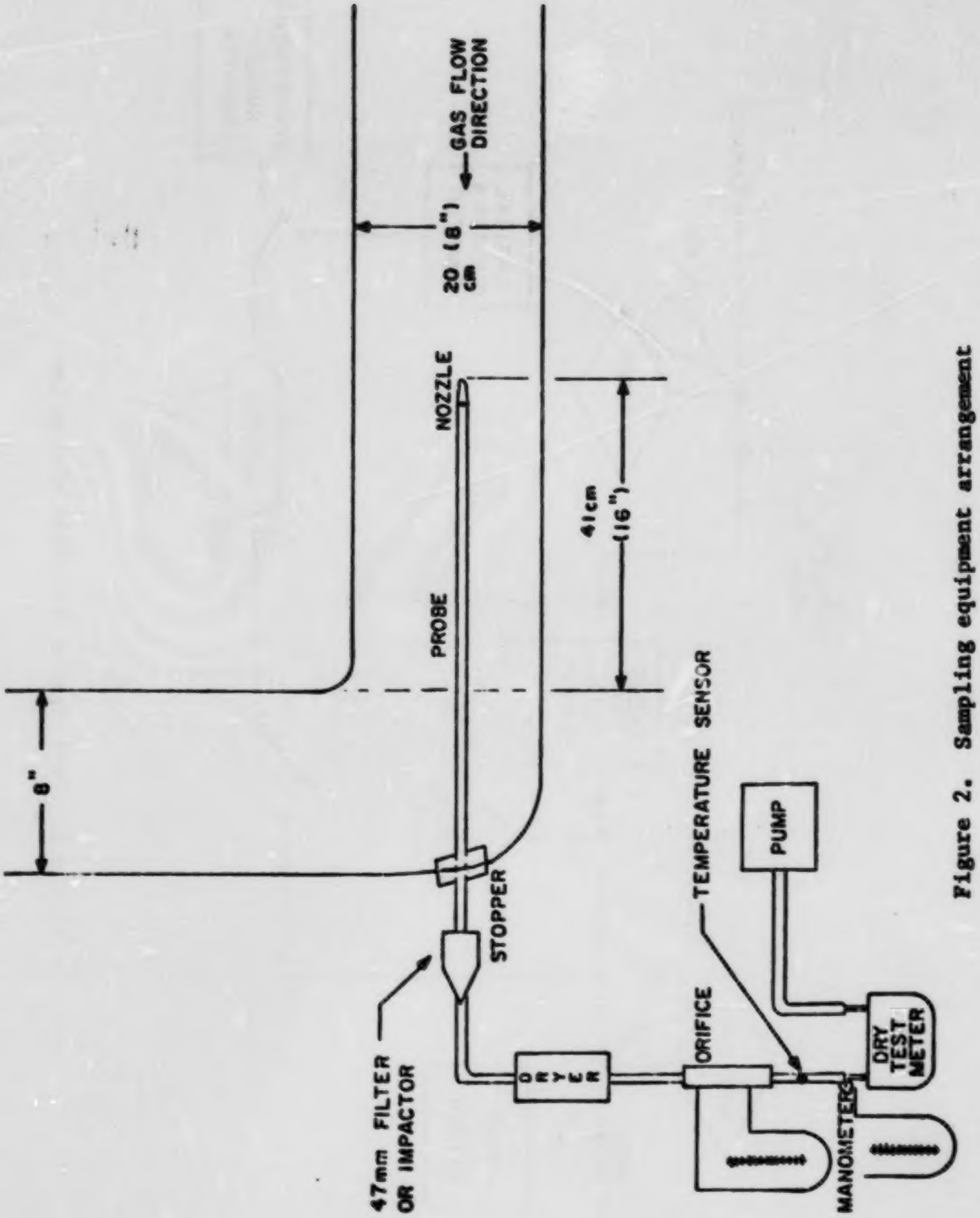
GAS FLOW DIRECTION
20 cm (8")
NOZZLE
41cm (16")
PROBE
8"
STOPPER
TEMPERATURE SENSOR
PUMP
47mm FILTER OR IMPACTOR
DRYER
ORIFICE
DRY TEST METER
MANOMETERS

Figure 2. Sampling equipment arrangement

(silica gel), a calibrated orifice, a dry test meter, and a pump. The temperature and pressure of the gas were measured between the calibrated orifice and the dry test meter.

The probe nozzles were placed two duct diameters from an upstream disturbance and greater than 8 duct diameters downstream from a disturbance. Therefore the sampling was done at an excellent location in the duct. All of the impactor and total mass determinations, except for two runs for which traversing was utilized, were made at the center of the duct.

A detailed description of our procedure for the use of the Andersen MK III impactors is given in Appendix B. Also, the results of a detailed intercomparison of our impactors with each other was presented in a previous GCA report entitled, "Dynactor Scrubber Evaluation", EPA-650/2-74-0830a, June 1975.[2] All impactor data is given in Appendix C.

It was determined that sufficient impactor sampling times were 15 minutes at the inlet and 2 hours at the outlet to produce loadings per impactor stage ≤ 15 mg.

For impactors and filters both the upstream and downstream samples were observed to be dry. Downstream drying was aided by the gas temperature increase produced by the heat from the blower of the CHEAF.

We also made particle size measurements with a Bausch and Lomb Dust Counter Model 40-1, and a Rich Model 100 Condensation Nuclei Counter. Details concerning our use of these instruments are given in Appendix D and Appendix E.

PROCEDURE

The estimated equilibrium concentration of solids was achieved by adding sufficient iron oxide to the recirculating water in the CHEAF, and the spray flow rates were adjusted. The blower was turned on and the unit allowed to reach an approximate equilibrium pressure drop. The dust feeder was started and more time was allowed to elapse to allow the concentration at inlet and outlet to approach equilibrium. (The sampling probes were covered to prevent them from catching dust when not sampling.)

Sampling was begun downstream. Upstream sampling was done thrice for impactor runs, centered on the midpoints of three equally-spaced time intervals. Total mass filter samples were obtained simultaneously for 20 minutes upstream and downstream. The filters and the impactor substrates were predried and preweighted. After a 24-hour drying period, they were weighed again to determine weight of material captured. For the condensation nuclei counter and the optical particle counter, samples were taken at the inlet and at the outlet at somewhat different times, and these samples were often drawn through a dilution system before going to the measurement devices.

The total gas flows through the ducts were determined at the inlet and outlet sampling locations for each run, utilizing velocity traverses. These measurements indicated approximately 20 percent leakage between the CHEAF inlet ducting and the outlet ducting. The effect of the leakage on results was factored into the analysis of data by multiplying the impactor dM/d(log d) by an appropriate correction factor. Total mass efficiency was determined utilizing a mass flux calculation which uses the total flow and concentration at each sampling point; therefore, no further correction was necessary.

SECTION V

RESULTS AND DISCUSSION

INITIAL FINDINGS REGARDING OPERATION OF CHEAF

Particle collection occurs in the CHEAF at a reticulated polyurethane foam filter which is placed over a rotating drum for support. The thickness of the foam is approximately 2.5 cm (1 inch). The maximum drum width is 10 cm (4 inches). Smaller drum widths can be obtained by covering a portion of the drum with strips of impermeable rubber. In this manner we were able to adjust the area of the foam through which the gas flowed, hence the face velocity at the filter.

Our initial plans to test the CHEAF at 3 different face velocities were hampered for two reasons. First, we were informed that in order for the demisters to operate efficiently it would be necessary to maintain the nominal flow of approximately 0.47 m^3/s (1000 cfm) through the unit. This, coupled with the limited maximum drum width, made it impossible to attain the low face velocities we initially intended to run. Second, the fan in the CHEAF unit was designed for one foam and could not pull 0.47 m^3/s (1000 cfm) through the two denser foams at the highest intended face velocity of 1000 cm/s (2000 fpm). In fact, the fan was unable to pull 0.47 m^3/s (1000 cfm) through the densest 80 pores per inch foam even at the intermediate face velocity of 500 cm/s (1000 fpm). Consequently, we were forced to run at approximately 20 percent lower face velocities than originally intended and were unable to run the 80 ppi foam at more than one face velocity.

We were also unable to run any of the foams at the lowest face velocities without modification of the CHEAF unit itself. This was accomplished by introducing filtered dilution air through a replacement plate which was placed downstream of the drum and upstream of the mist eliminator. In this manner we were able to pull the reduced volume of air through the CHEAF filter drum and maintain the needed air flow through the demister, thus insuring its proper operation.

Utilizing a combination of varying filter drum width and addition of dilution air beyond the drum, we were able to achieve 3 levels of face velocities, varying between 243 cm/s and 840 cm/s (478 and 1650 fpm).

TESTS WITH 65 PORES PER INCH FOAM

CHEAF Set-Up

The majority of the tests performed were with the 65 pores per inch foam since it is the usual foam used in the CHEAF. Tests performed with this foam included impactor and total mass filter runs up and downstream as well as optical particle counter and condensation nuclei counter measurements.

Initial flow testing with the 65 ppi foam determined that a 6.35 cm (2.5 inches) wide strip of exposed foam at the CHEAF drum yielded the highest face velocity possible with a corresponding total volume flow at the fan inlet of approximately 0.47 m^3/sec (1000 acfm). The initial pressure drop across the filter drum at these conditions was 61 cm WC (24 in. WC). Running the CHEAF at these conditions, with the addition of 6 g/min of iron oxide at the inlet and 0.3 percent by volume of iron oxide in the recirculation water, rapidly increased the pressure drop across the filter drum to 66 cm WC (26 in. H_2O). This increase in pressure drop across the filter drum caused a corresponding decrease in the total volume flow of air through the CHEAF, bringing the nominal conditions of face velocity down to approximately 800 cm/sec or 20 percent lower than initially planned.

We were forced to settle for this compromise because the fan was somewhat underpowered and was not capable of pulling more than approximately 0.38 m^3/s (800 acfm) through the 65 ppi foam with a face velocity of 800 cm/s.

Overall Efficiency Runs

Overall Efficiency Runs at Nominal Conditions (3222 Series) - Two sets of total mass and impactor runs were made at the nominal condition (3222) before the pressure drop across the filter drum rose noticeably. Two more pairs of runs were made with impactors and total mass filters. This time the total mass filters were attached to button hook type nozzles and collected by traversing in the duct as called for in EPA Method 5.[1] During these tests the pressure drop across the filter drum had risen to 70 cm WC (27.5 in. WC), and the flow through the CHEAF was consequently diminished somewhat along with the face velocity. The overall penetration (total mass) for these runs at nominal conditions are given in Table 3.

Table 3. OVERALL PENETRATION OF THE CHEAF AT NOMINAL CONDITIONS (3222 SERIES OF RUNS)

Run no.	Penetration, %	Pressure drop, cm (in.) WC
3222-1	5.87	66 (26)
3222-2	5.04	66 (26)
3222-3	5.65	70 (27.5)
3222-4	4.99	70 (27.5)

Overall Efficiency Runs at Increased Water Spray Rate (3212 pair) - A secondary set of tests were performed to evaluate the effect of water usage of the CHEAF upon overall and fractional efficiency. These included a higher water spray rate and both higher and lower water recycle rates.

The nominal water spray rate was chosen as 4.2 liters per minute (1.1 gpm) or approximately 11 lpm/m^3/sec (1.4 gpm/1000 cfm). This is the water rate at which the 3222 series of tests were run. Two runs were performed at a higher water spray rate of 5.75 liters per minute (1.5 gpm) or approximately 15 lpm/m^3/sec (1.9 gpm/1000 cfm). Two total mass filter and impactor efficiency runs were performed at this higher water spray rate, and are numbered as the 3212 series of runs. The penetration for the total mass filter runs are given in Table 4, and it can be seen that they average somewhat lower than for the 3222 series of runs; penetration decreased as liquid-to-gas ratio increased.

Table 4. OVERALL PENETRATION OF CHEAF AT HIGHER WATER CONSUMPTION RATE OF 5.75 LITERS PER MINUTE (1.5 gpm) (3212 SERIES OF RUNS)

Run no.	Penetration, %	Pressure drop, cm (in.) WC
3212-1	5.24	70 (27.5)
3212-2	4.89	70 (27.5)

Overall Efficiency Runs at Simulated High and Low Water Recycle Rates (3221 and 3223) - The second water-related parameter which was investigated was the rate of recycling water through the CHEAF system. It is common scrubber practice to maintain a tank or reservoir of water from which water is drawn for the sprays and into which is charged the collected spray water. This substantially reduces water consumption and hence reduces the cost of water and its subsequent treatment. Therefore, it is important to determine how high a solids loading (corresponding to a high water recycle rate) can be tolerated before the solids in the water begin to substantially contribue to the penetration. If a constant amount of particle-bearing water is entrained by the scrubber off-gases, the amount of solids escaping into the off-gases with the water would be proportional to the solids loading in the scrubber water.

In order to determine the effect of solids loading on the CHEAF's performance, we ran a series of two paired runs each at a lower and higher than nominal solids loading. These tests spanned a tenfold difference in solids loading which corresponded directly to a tenfold difference in water recycle rate. Since the CHEAF unit was not set up to run with a continuous water addition and water removal flows, we ran tests on a batch type basis, periodically removing solids-laden water and replacing it with clean water to maintain a fairly steady known solids level in the recirculation tank.

At nominal conditions (3222), we maintained a solids level in the tank of 0.3 percent volume fraction, which was to be equivalent to a water removal/replacement rate of 1 lpm/m^3/s (0.125 gpm/1000 cfm). We ran two total mass filter and impactor tests for penetration at a higher and lower solids in water volume fraction. The lower volume fraction was equivalent to 3 lpm/m^3/s (0.375 gpm/1000 cfm), the 3223 series. The higher volume fraction was equivalent to 0.3 lpm/m^3/s (0.0375 gpm/1000 cfm), the 3221 series.

The pressure drop across the drum remained the same for the lower volume fraction runs (3223) as it had been for the previous nominal condition runs (3222), namely, 70 cm WC (27.5 in.); however, for the higher volume fraction runs (3221), the pressure drop across the drum rose to 72 cm WC (28.5 in.), thus clouding somewhat the explanation of the results presented here in Table 5.

Table 5. OVERALL PENETRATION OF CHEAF AT THREE LEVELS OF SOLIDS IN RECIRCULATION WATER

Run no.	Penetration, %	Pressure drop, cm (in.) WC	Volume fraction of solids in water, %
3222 Series	5.38	68 (26.75)	0.3
3221-1	4.15	72 (28.5)	1.0
3221-2	4.64	72 (28.5)	1.0
3223-1	3.07	70 (27.5)	0.1
3223-2	3.76	70 (27.5)	0.1

Although the results are somewhat obscured by the variations in pressure drop across the filter drum, it can be seen clearly from runs 3221-1 and 2, and 3223-1 and 2, that the penetration depends upon volume fraction of solids in the recirculation water. Even with a higher pressure drop, the higher solids runs (3221-1 and 2) had nearly a 29 percent higher average overall penetration than the lower solids (3223-1 and 2) runs. This indicates that entrained water droplets which escape the demisters are a substantial source of penetration in the CHEAF.

Overall Efficiency Runs at Lower Face Velocities (2222 and 1222) - Two other tests were run with the 65 ppi foam, and these were considered to be primary tests belonging in the principal test matrix. These two tests involved operating the CHEAF at lower-than-nominal face velocities of 530 and 243 cm/s (1040 and 480 fpm). The first or higher velocity tests (2222) were accomplished by exposing 10 cm (4 in.) of the foam filter material on the drum. With this new increased drum width, the fan in the CHEAF was able to pull 0.387 m^3/s (820 cfm) through the filter drum at a pressure drop of 48 cm WC (19 in. WC), yielding a 530 cm/s face velocity. A total mass and impactor efficiency test was run at these operating conditions.

The lowest face velocity tests (1222) were accomplished with much more difficulty, requiring a modification of the CHEAF itself, as explained in the Introduction. Efficiency tests using total mass filters and impactors were run as well as measurements with an optical particle counter and a condensation nuclei counter. The face velocity for this test was 243 cm/s and the pressure drop across the filter drum was 18 cm WC (7 in.). Results of the total mass filter efficiency tests are given in Table 6, and as would be expected, the penetration rises with decreasing face velocity and/or pressure drop.

Table 6. OVERALL PENETRATION FOR THE 65 PPI FOAM AT THREE LEVELS OF FACE VELOCITY

Run no.	Penetration, %	Pressure drop, cm (in.) WC	Face velocity, cm/sec
3222 Series	5.38	68 (26.75)	797
2222	6.20	48 (19)	530
1222-A	22.45	18 (7)	243

As can be seen in Figure 3, however, the total penetration appears to level off at the intermediate face velocity, indicating perhaps some optimum face velocity exists where the CHEAF will achieve the maximum particulate collection per unit of energy. These results are somewhat clouded by the lowest face velocity run (1222-A) since we were unable to decrease the water spray rate per unit time, hence the ratio of water spray to volume of gas treated is elevated by over a factor of 2 for this run. The effect of using a higher water spray rate in our earlier tests (3212) indicated that a somewhat lower penetration might be expected. Since the penetration at this low face velocity is very high compared to the higher face velocity runs, the effect of the excess water spray is unlikely to change the overall appearance of curves in Figure 3.

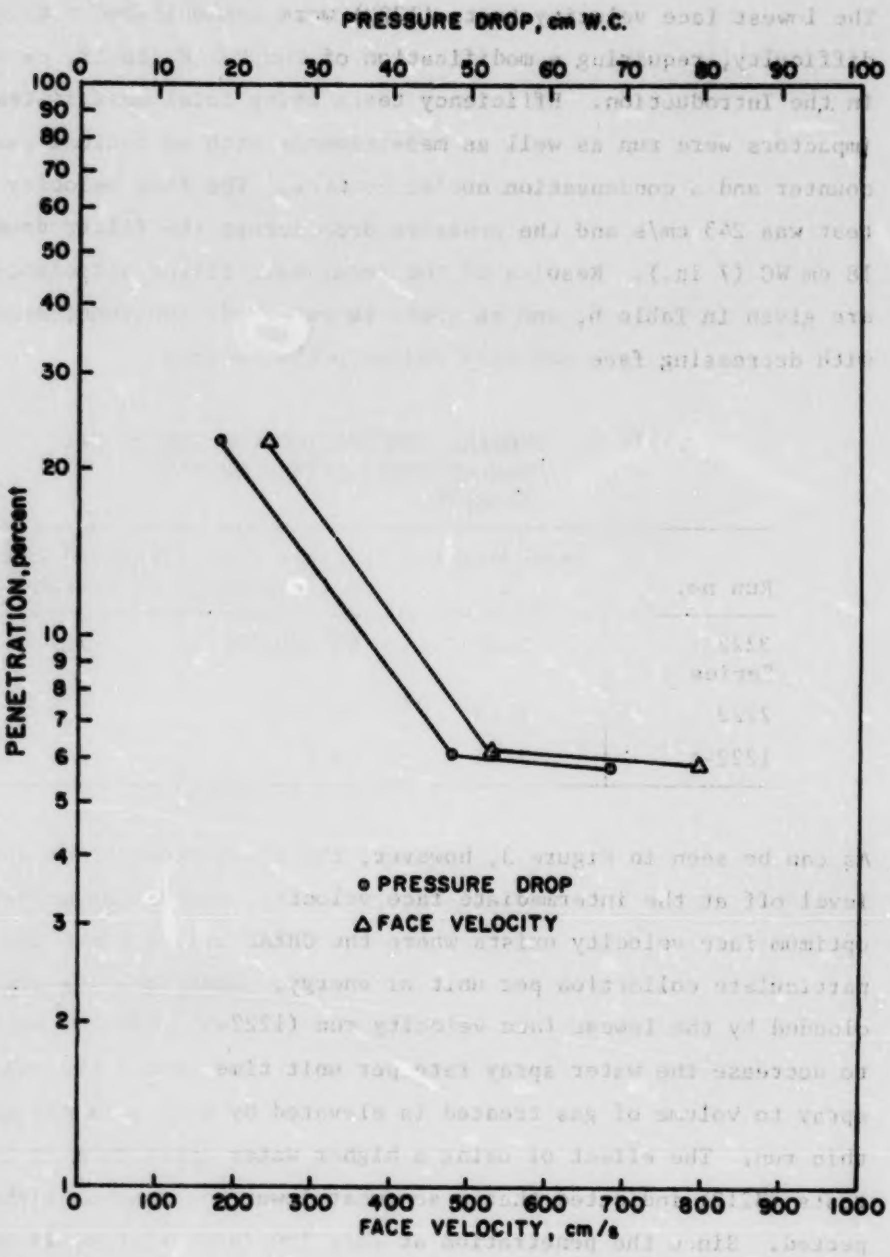

Figure 3. Penetration versus face velocity and pressure drop for the 65 ppi foam

Fractional Efficiency Tests With Andersen Impactors

Fractional Efficiency for Runs at Nominal Conditions - As we have stated, Andersen impactors were run for each of the conditions previously mentioned. The impactor data were ultimately utilized to derive fractional efficiency information presented here as curves of penetration versus particle size. Appendix B gives the details.

Figure 4 shows one of the inlet particle size distribution results, as obtained from the Andersen impactor, using the manufacturer's calibration. The mass median aerodynamic diameter is about 1.1 μm and the geometric standard deviation is about 2.2, although the distribution is clearly truncated in the upper particle size range, thus substantially different from a log-normally distributed aerosol. Because about 85 percent of the particle mass was less than 3 μm aerodynamic diameter, the iron oxide was a convenient test dust for fine particle efficiency measurements.

A typical data sheet for the tests is shown in Table 7, and the data sheets for all other impactor runs are given in Appendix C. This sheet corresponds to the size distribution results shown in Figure 4. From the cumulative distributions one can calculate the fraction of particles in any size interval, and thus compare inlet and outlet concentrations as a function of particle size to obtain penetration versus particle size. Figure 5 gives the inlet and outlet concentrations for the same test (again number 3222-3) at the usual operating conditions for the CHEAF (nominal flow rate, foam pores-per-inch rating, water-spray-to-gas flow ratio) in terms of the mass concentration per logarithmic interval, dm/d (log d_p). On this basis the penetration of any particle size is just the ratio of the outlet value of dm/d (log d_p) to the inlet value. The outlet value of dm/d (log d_p) has been corrected for air leakage into the CHEAF, and it is the corrected value which has been plotted in Figure 5.

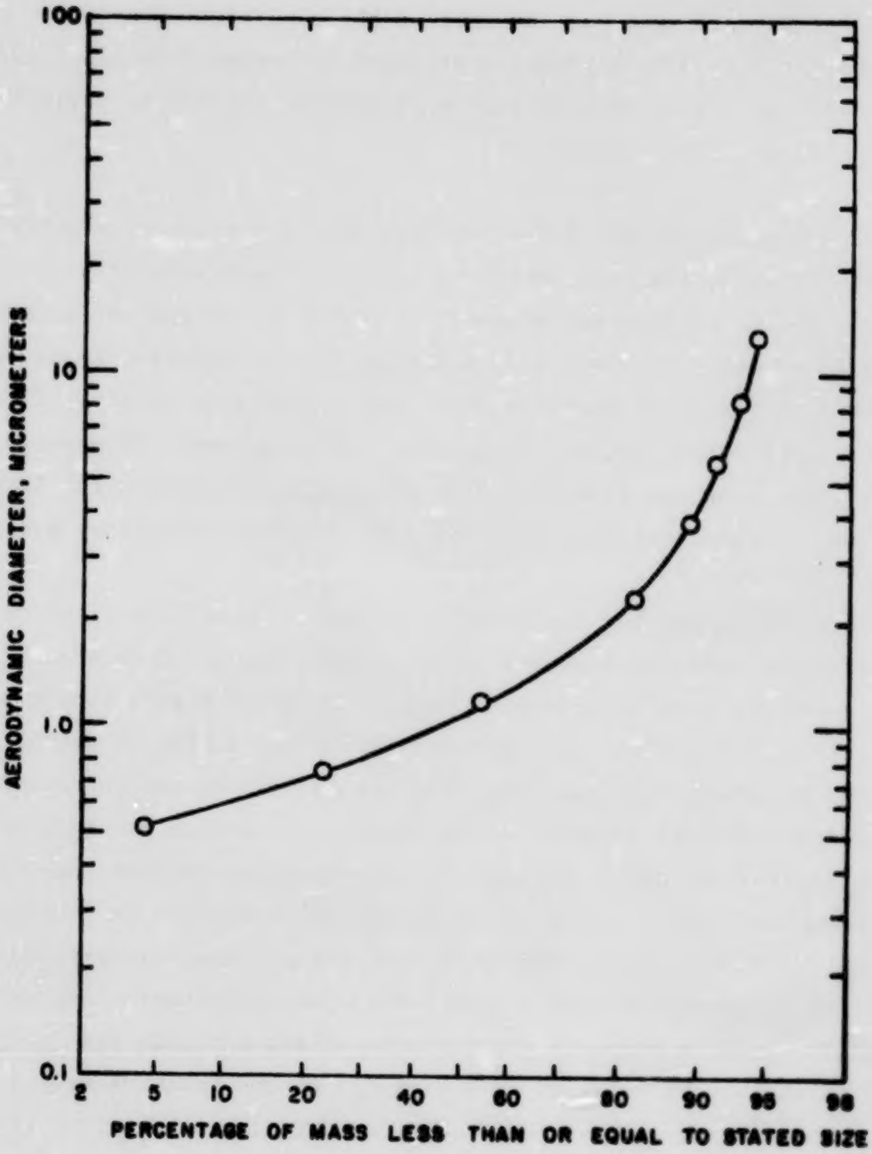

Figure 4. Inlet particle size distribution, CHEAF test number 3222-3

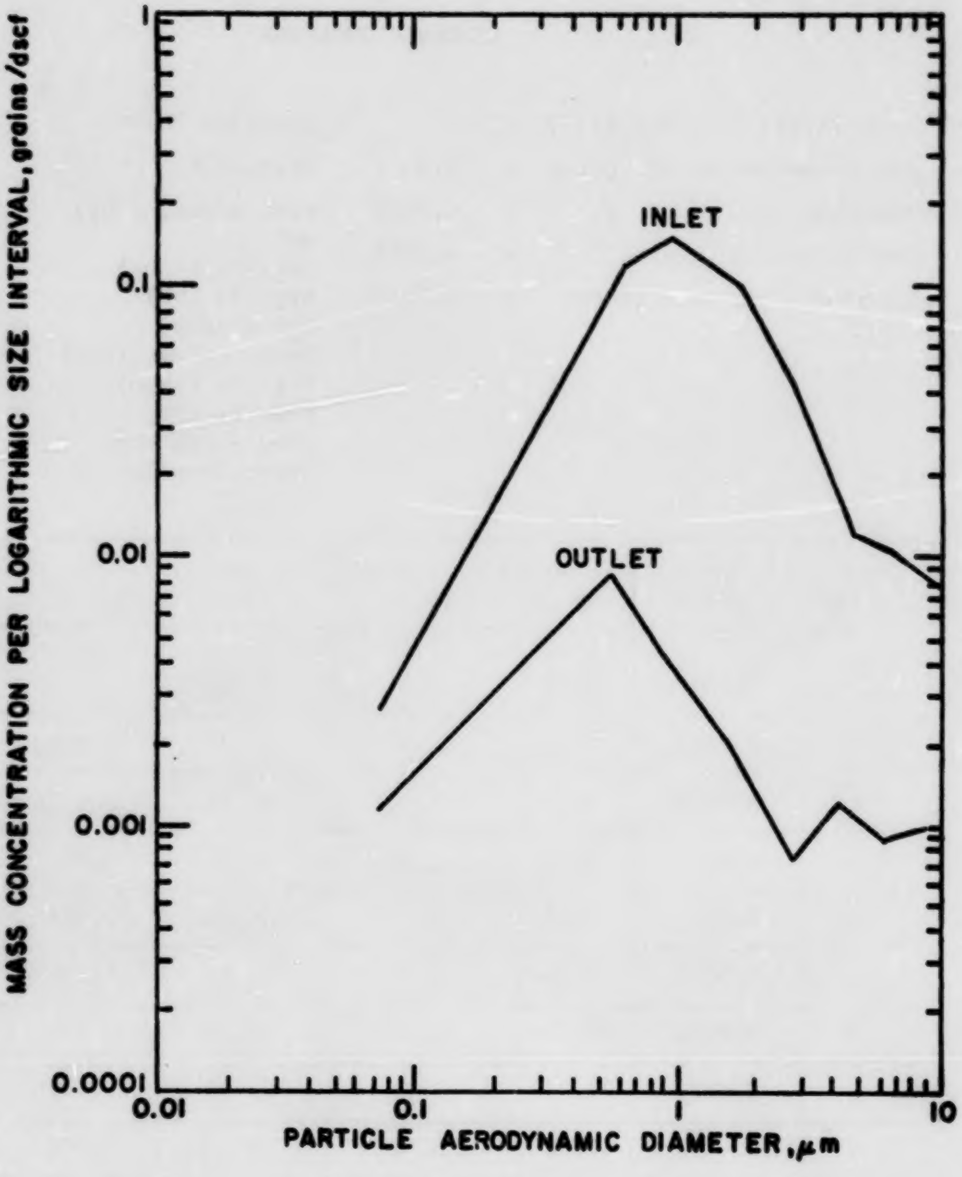

Figure 5. Inlet and outlet concentration distributions for run 3222-3

Table 7. SAMPLE DATA SHEET FOR IMPACTOR TESTS OF CHEAF COLLECTION EFFICIENCY

ANDERSEN IMPACTOR

Date 11/12/75 Run # (3222-3)
Sample volume at STP (ft^3) = 10.9630
Moisture (%) = 0.9492
Concentration (grains/ft^3) = 0.1040
Impactor flow rate (acfm) = 0.5529

Location Inlet
Orifice E
Bar. press. ("Hg) = 29.93
Mw[a] = 29
Avg. Pm (-"Hg) = 1.5
Avg. Tm (°F) = 76
H_2O (grams) = 2.2
Meter volume (ft^3) = 11.56
Avg. Ps ($\pm H_2O$) = -1
Avg. Ts (°F) = 74
Time (minutes) = 20
Correction factor = 1

Stage	Net weight, grams	% on stage	Size cutoff, µm	% ≤ stated size	dm/d log D	Geo. mean, µm
Probe & expander	0.0032	4.37		95.63		
0	0.0012	1.64	12.91	93.99	0.0070	10.21
1	0.0010	1.37	8.07	92.62	0.0098	6.61
2	0.0012	1.64	5.41	90.98	0.0125	4.51
3	0.0014	1.91	3.75	89.07	0.0366	2.96
4	0.0053	7.24	2.34	81.83	0.1018	1.69
5	0.0203	28.73	1.22	54.10	0.1503	0.95
6	0.0227	31.01	0.74	23.99	0.1170	0.61
7	0.0137	18.72	0.51	4.37	0.0027	0.07
F	0.0032	4.37				
Total	0.0732					

[a] These abbreviations are explained in Appendix B.

If the predominant collection mechanisms for the CHEAF are interception and inertial impaction, one would expect the penetration to decrease with increasing particle size. If diffusion is important, one would expect perhaps an improvement in collection efficiency (or at least a change in slope of collection efficiency versus particle size) at the smallest particle sizes (≤ 0.3 μm). One more complication, at least, will arise. Some fraction of particulate material which has been captured in the scrubbing liquid may escape the demisters, either because the droplets were too fine to be captured or because the liquid has been atomized from some surface because of air shear. Figure 6 shows the penetration versus particle size curve for a test at the nominal conditions with and without correction for spray solids. For the uncorrected values, up to about 3 μm, one has the expected increased efficiency (decreased penetration) versus increasing particle size. The penetration then rose to a nearly constant level for particles larger than about 5 μm aerodynamic diameter. Because we thought such behavior might occur, we made a test near the very beginning without a dust feed with the scrubber in the nominal operating mode (including suspended material in the recirculating water) to have an estimate of the extent to which reentrained droplets (or those not captured at all) would affect penetration.

Curve (4) in Figure 7 shows the results of the test without inlet aerosol, just described. Curves (1) and (2) in Figure 7 are the inlet and outlet concentrations for the test with dust generated at the inlet, and curve (3) is the outlet concentration for that test minus the outlet concentration found when no aerosol was generated at the inlet. The penetration calculated from the corrected curve (3) and the inlet curve (1) is also shown in Figure 6. This is strong evidence for the hypothesis that most penetration of the particles larger than 3 μm or so was due to reentrainment and/or imperfect demisting. When dust is present at the inlet, the contribution from reentrainment and imperfect demisting would be somewhat greater. This is because the concentration of the particulate material in the drops

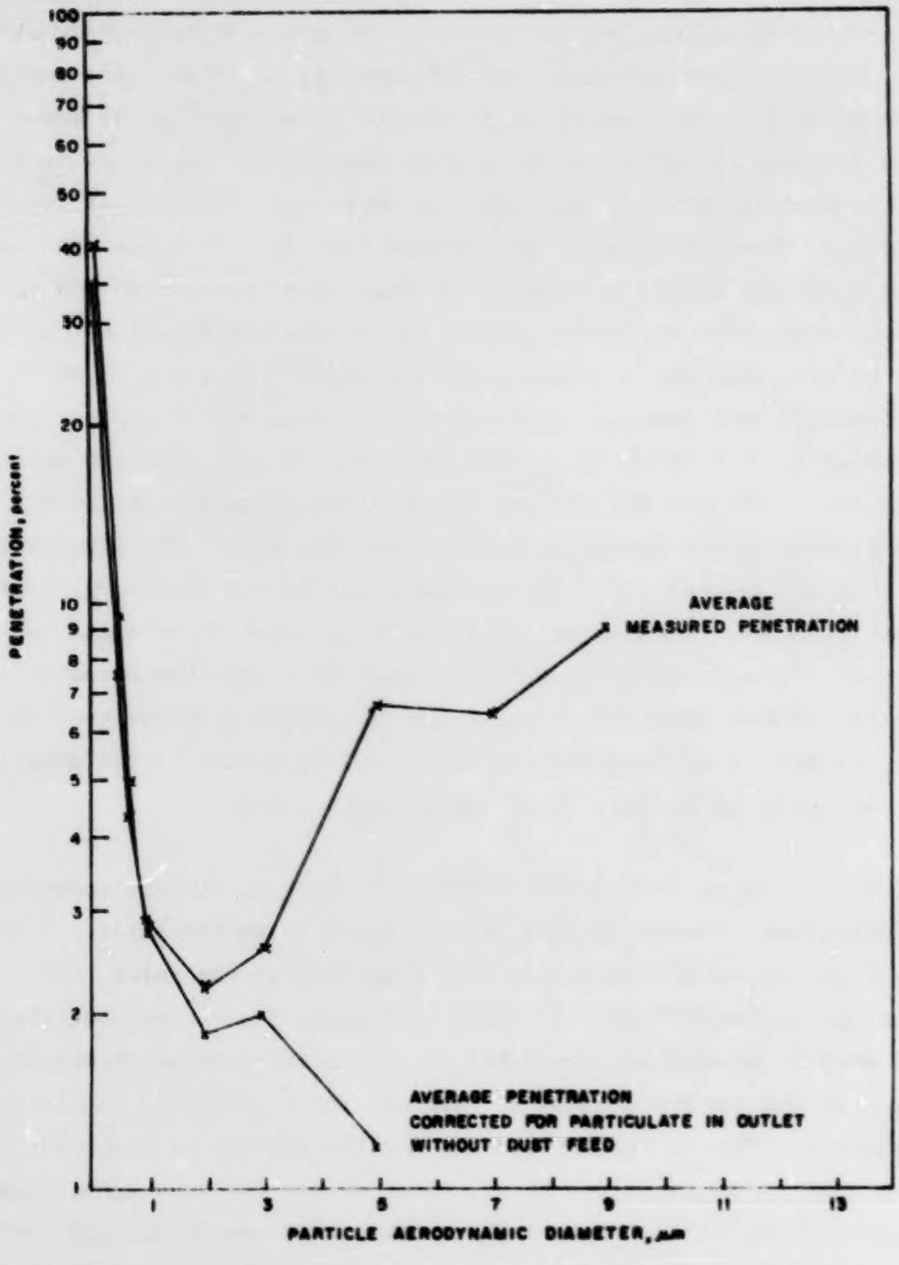

Figure 6. Penetration versus particle size for nominal conditions (average of 3222 series of runs), corrected for reentrainment and uncorrected

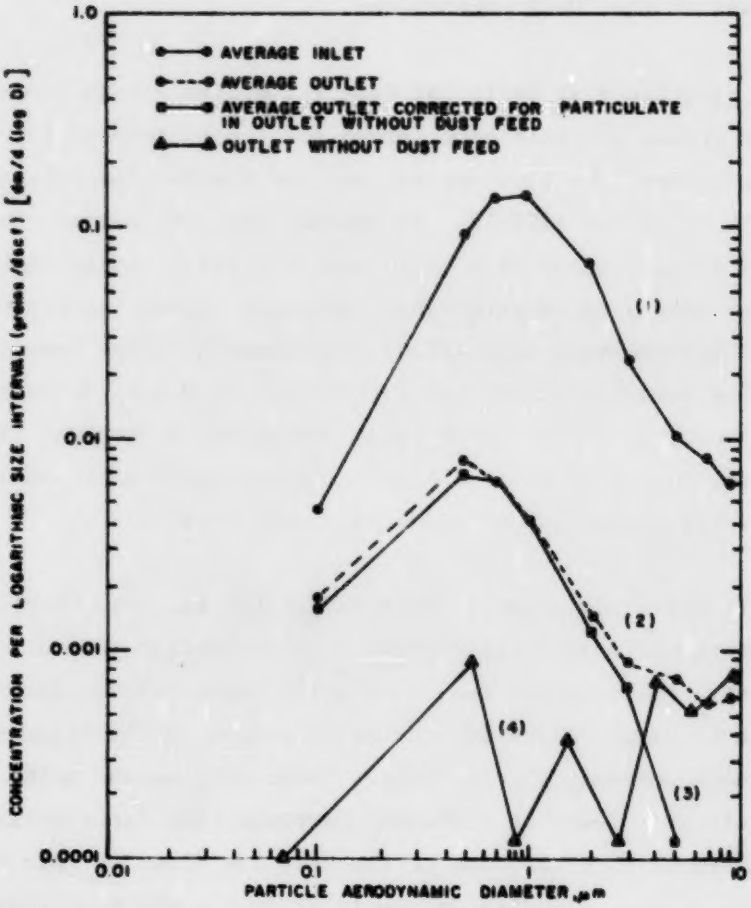

Figure 7. Inlet and outlet mass concentration distributions

and on the collection surfaces will be somewhat higher than the average equilibrium concentration in the recirculating water on account of the particulate material just captured. This may well explain the change in slope of percent penetration for particles larger than 0.5 μm in Figure 6.

In reporting the CHEAF penetration we have not subtracted the material produced by reentrainment and/or imperfect demisting, for this is an integral part of the CHEAF performance.

Fractional Efficiency at Different Face Velocities - Figure 8 contains penetration versus particle size curves for the average of the tests at nominal conditions, the 3222 series, and for the two lower face velocity runs, namely, 2222 and 1222-1a. It can be seen that curves (3) and (2) have a very similar shape with their main difference being that they are at different levels of penetration. These two curves correspond to the highest and intermediate face velocities, therefore, the overall penetration being somewhat higher for curve (2) than curve (3) is as expected if impaction is the predominant collection mechanism. The similarity of the curves in their shape indicates that the collection mechanisms are essentially unchanged for these two conditions.

Curve (1) is very dissimilar to both curves (2) and (3). First of all, the data indicated more large particles at the outlet than at the inlet. Unfortunately, the impactor runs from which curve (1) was derived contain some zero weight gains for the upper stages of the inlet impactor, which was most unusual for our tests. These zero weight gains may well be the result of a somewhat different particle size distribution at the CHEAF inlet sampling point, due to the very low flow for this test. The very low flow or velocity in the inlet duct could have caused the larger particles to settle out in the ducting before reaching the inlet sampling point. If this was the case, then the appearance of large particles at the outlet due to reentrainment of solids-laden spray water

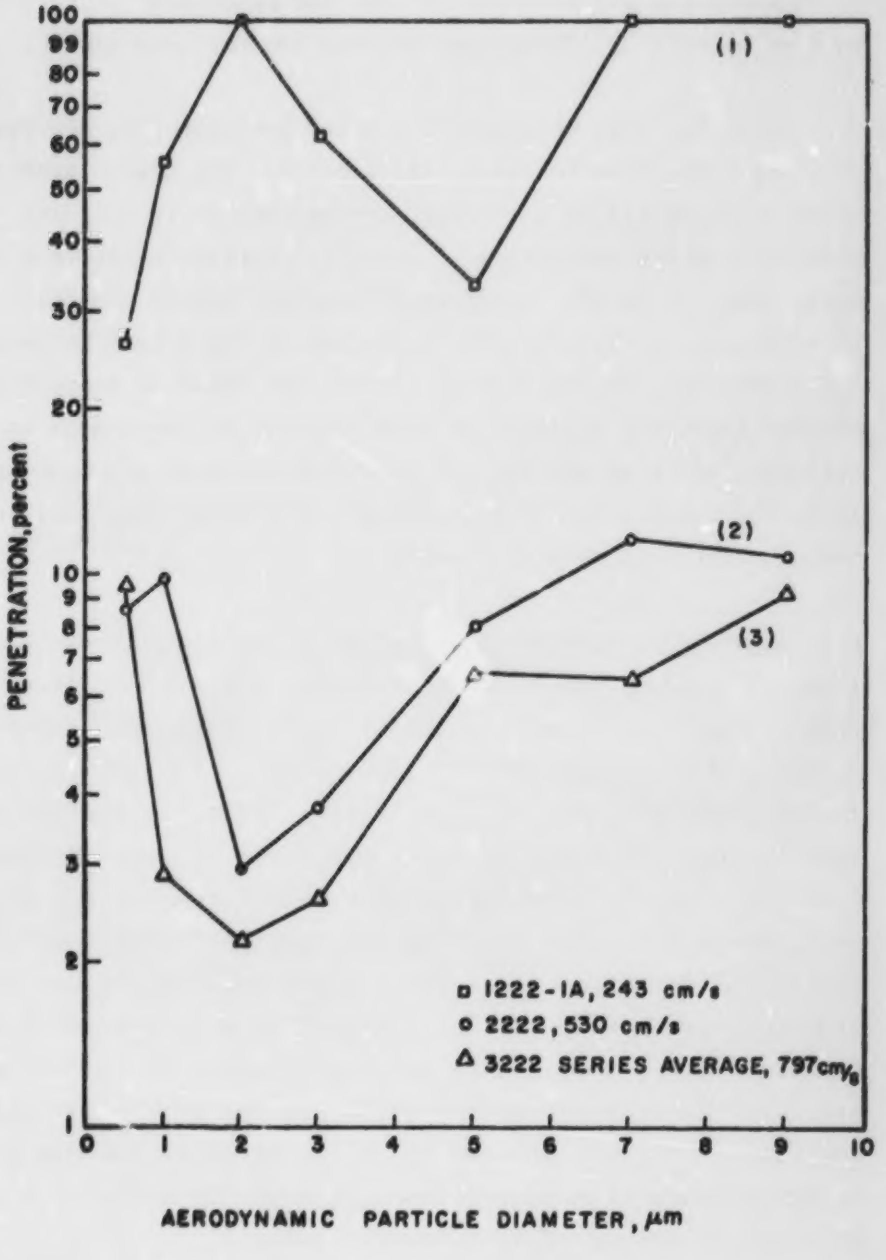

Figure 8. Penetration versus particle size for 65 ppi foam at three levels of face velocity

could cause the greater than 100 percent penetration observed, which in fact we plotted as 100 percent penetration for convenience.

Looking at the bulk of curve (1), below 5 microns, we see penetration behaving oppositely to curves (2) and (3). The lowest penetration in curves (2) and (3) at 2 microns, corresponds to the highest penetration of greater than 100 percent for curve (1). Extrapolating from the changes in going from (3) to (2), we expected somewhat higher penetrations in all size classes for (1) but with a minimum in the 1 to 3 μm range— we observe the former but not the latter. Either the CHEAF is operating very unlike nominal conditons at this low face velocity or the change in conditions seriously affected our ability to obtain accurate and meaningful data. Later the results for 45 ppi foam at three flow rates will be presented; these curves show no such anomaly.

Fractional Efficiency at Higher Water Spray Rate — Figure 9 contains fractional efficiency curves for the CHEAF at nominal conditions (3222) and with a higher water spray rate (3223). Curve (1) is for the nominal conditions, liquid-to-gas ratio $0.19 \times 10^{-3} m^3/m^3$ and curve (2) is for the higher ratio (L/G) of $0.26 \times 10^{-3} m^3/m^3$. The two curves are very similar, both in shape and magnitude. The two points of major difference are at 7 microns where the penetration is much higher at the higher water spray rate, and at 1/2 micron where the penetration is much lower at the higher flow rate. The higher penetration at 7 microns may be due to poor mist eliminator performance, in which case it is a problem which could be corrected by better design. The lower penetration for the 1/2 micron particle size seems to represent an improvement in the CHEAF's performance on fine particles. Only one impactor run of two contained useable data, therefore we cannot place as much confidence in curve (2) of Figure 9 as in curve (1) which is the average of four impactor runs.

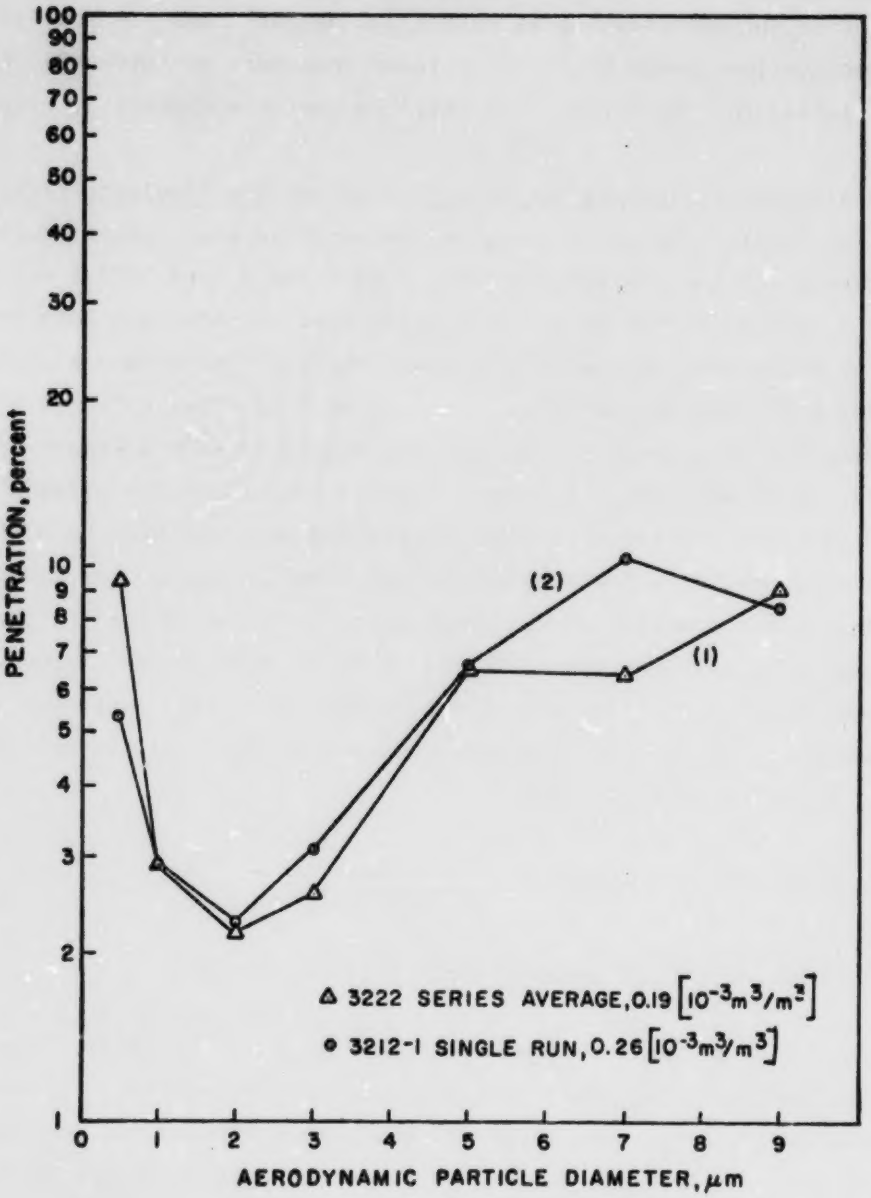

Figure 9. Penetration versus particle size for 65 ppi foam at two water spray rates (two liquid-to-gas ratios)

The total mass runs indicate only a very slight improvement in efficiency for the higher water spray rate (3212 series) runs, indicating that the penetration should be lower at least somewhere on curve (2), further evidence for the better fine particle particle capture at higher L/G.

Fractional Efficiency for Runs at High and Low Simulated Water Recirculation Rates - Figure 10 contains the particle size versus penetration curves for the two sets of runs, 3221-1 and 2, and 3223-1 and 2, where the solids loading in the tank recirculation water was made both higher and lower than nominal conditions. The two curves have a similar shape for particles smaller than 3 µm. Above 3 microns, curve (1), which corresponds to a lower solids loading, begins to show a lesser degree of penetration than curve (2). These results from these two pairs of runs further strengthen the argument that reentrained particle made up most of the larger particles found at the outlet. The curves are as expected if there is a given fraction of the water spray droplets by-passing the demisters and being carried through to the outlet. Under these circumstances, we would expect that the overall occurrence of larger particles at the outlet would be increased if the spray water contains a higher solids loading, and this is what was observed.

TESTS WITH THE 45 PORES PER INCH FOAM

Overall Efficiency at Three Face Velocities

The 45 pores per inch foam was tested at three levels of face velocity at the nominal water spray rate and water solids loading. These tests included one set of impactors and total mass filters per condition, and optical particle counter and condensation nuclei counter measurements of the highest and lowest face velocity. The three runs were numbered 3122, 2122, and 1122 from highest to lowest face velocity, respectively. The results of the total mass tests were as shown in Table 8 and presented graphically in Figure 11.

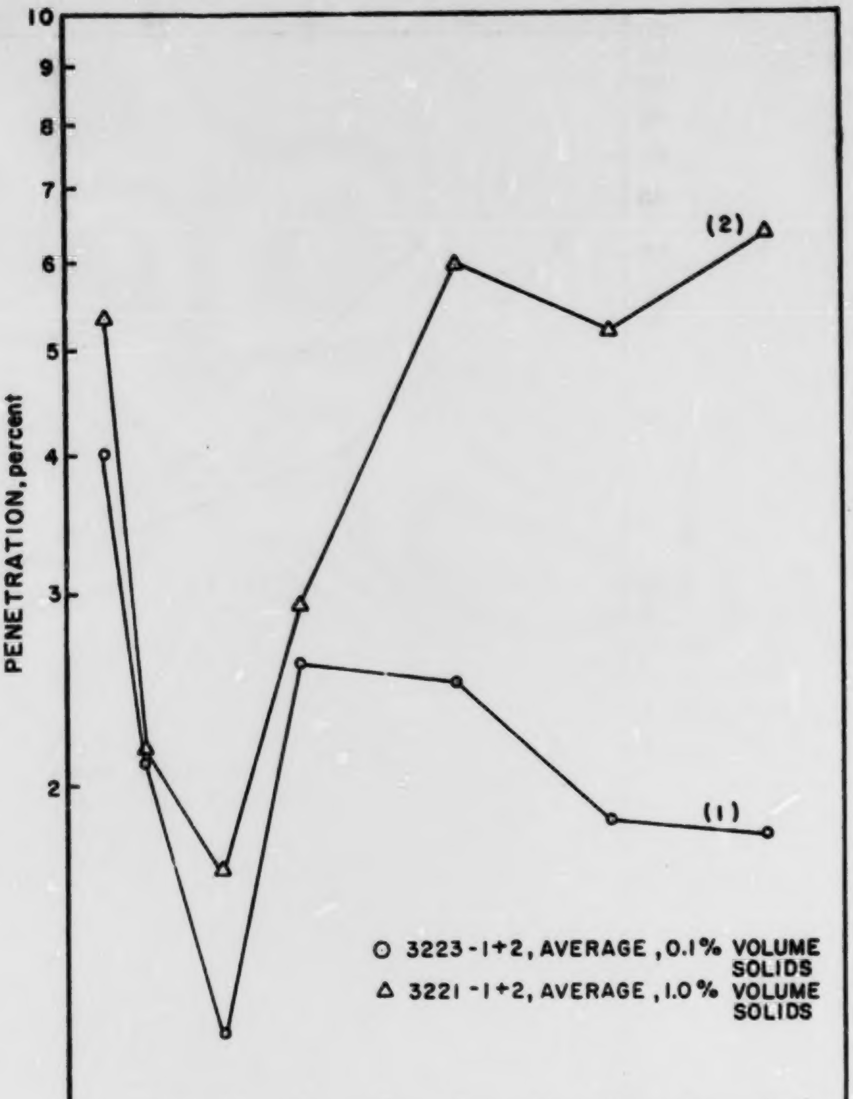

Figure 10. Particle size versus penetration for two different solids loadings in recirculation water

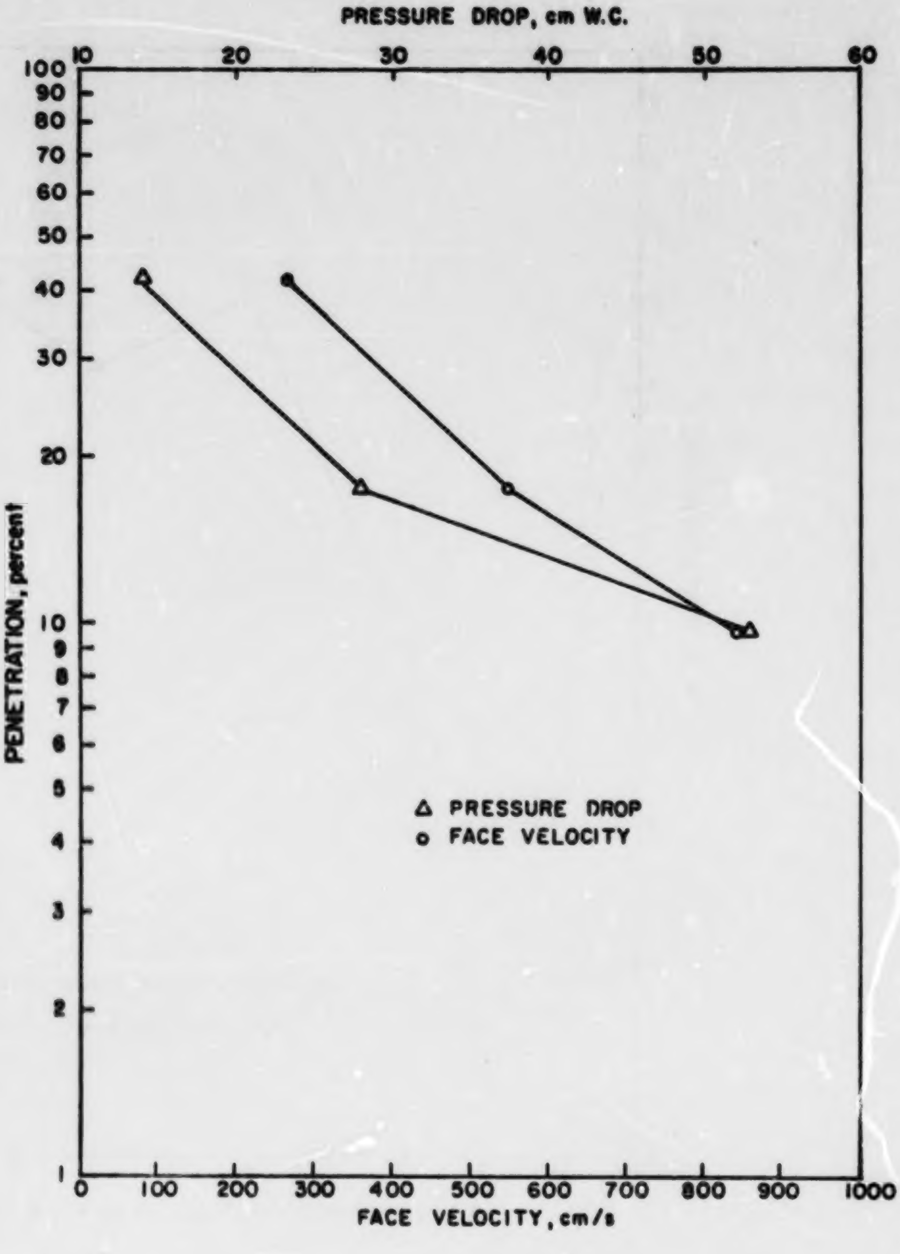

Figure 11. Penetration versus pressure drop and face velocity for the 45 pores per inch foam

Table 8. OVERALL PENETRATION OF THE CHEAF WITH THE 45 PORES PER INCH FOAM AT THREE LEVELS OF FACE VELOCITY

Run no.	Penetration, %	Pressure drop, cm (in.) WC	Face velocity, cm/s
3122	9.61	53 (21)	840
2122	17.45	28 (11)	548
1122	41.52	14 (5.5)	262

Comparing Figure 11 with Figure 3 (for 65 ppi foam) we note that both show decreasing penetration as pressure drop (or face velocity) increases, as one expects for collection dominated by impaction. For a comparable pressure drop, however, the 65 ppi foam has a higher efficiency than the 45 ppi foam, an important advantage for the 65 ppi material.

Fractional Efficiency at Three Face Velocities

Figure 12 contains the fractional penetration curves for the three different face velocity runs with the 45 ppi foam. Curves (2) and (3) have very similar shapes with a minimum penetration occurring at 2 microns. The penetration to the right of the minima on curves (2) and (3) is believed due to reentrainment. As the face velocity increases, smaller droplets are reentrained, becoming smaller particles once dry. Curve (1) appears to have a contribution from reentrained particles which is predominant even at 1 μm. As the face velocity increases, the capture of the droplets before the demister section has apparently increased (the demisters were operated at constant flow).

Generally the curves occur at varying overall penetration levels are as expected, that is, penetration was highest for the lowest face velocity, which is consistent with the hypothesis that impaction was the dominant particle collection mechanisms for particles ≳ 1 μm aerodynamic diameter.

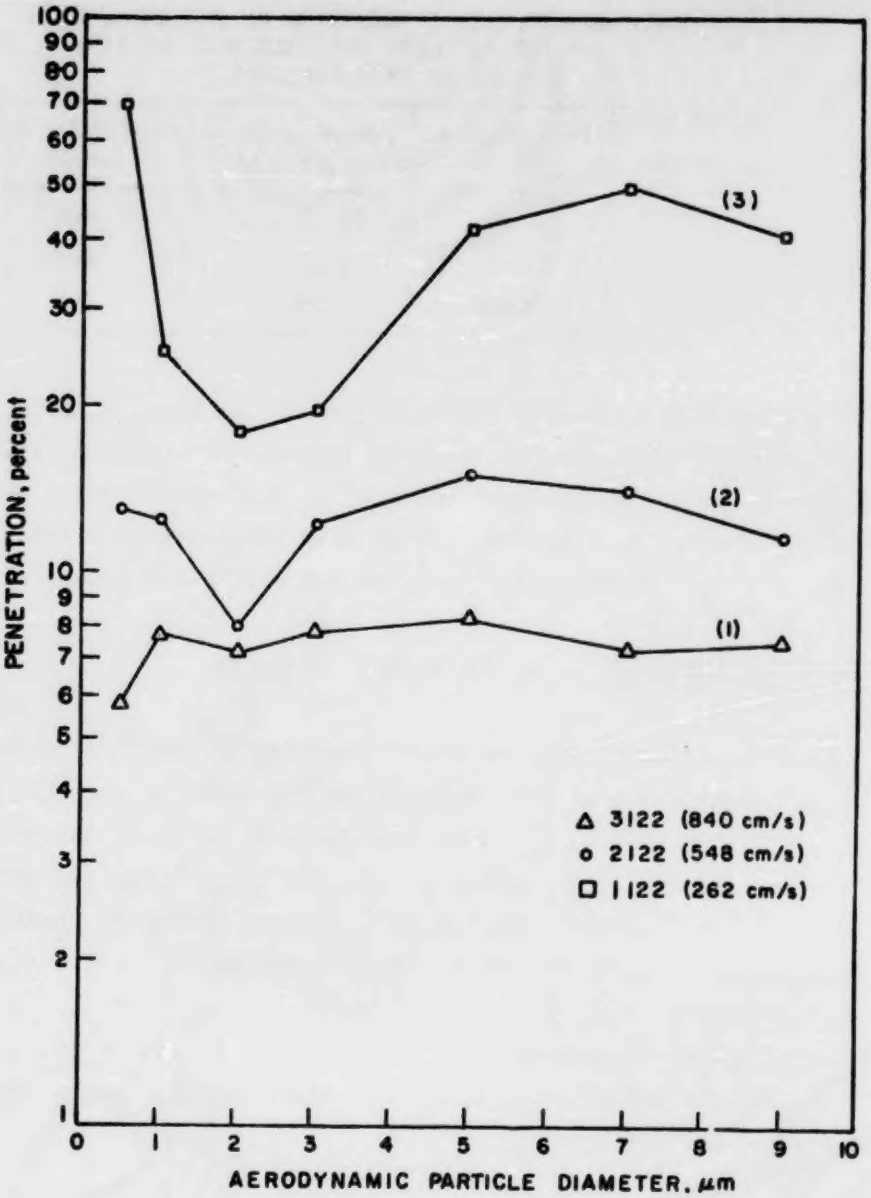

Figure 12. Penetration versus particle size for the 45 ppi foam at three levels of face velocity

Overall, the penetration is very high for each particle size, indicating that the 45 ppi foam is not as efficient as the 65 ppi foam for the CHEAF system.

TESTS WITH THE 80 PORES PER INCH FOAM

Overall Efficiency Run

We were unable to test the 80 ppi foam at more than one face velocity, as previously explained, due to the high resistance of that foam compared with the fan power in the CHEAF unit. Consequently, we ran a total mass efficiency test and an impactor or fractional efficiency test for the low face velocity we were able to achieve, 331 cm/s.

The results of the total mass test indicated an overall penetration of 3.67 percent at a pressure drop of 72 cm (28.5 in.) WC, and a face velocity of 331 cm/s. This low overall penetration was as expected for the noticeably denser foam and the high pressure drop. The low face velocity of 331 cm/s did not seem to have as important an effect upon the penetration with the 80 ppi foam as the high pressure drop across that foam. The 80 ppi foam had lower penetration than the 65 ppi foam for comparable pressure drop, but the volume flow per filter area was also lower.

Fractional Efficiency Run

The fractional efficiency curve for the impactor run is plotted in Figure 13. The curve displays the general shape of the same curves for the 65 and 45 ppi foams, indicating that the collection mechanisms are similar. It is interesting to note that the lowest penetration occurs at 2 microns for essentially all of the foams and face velocities tested, including this most dense foam.

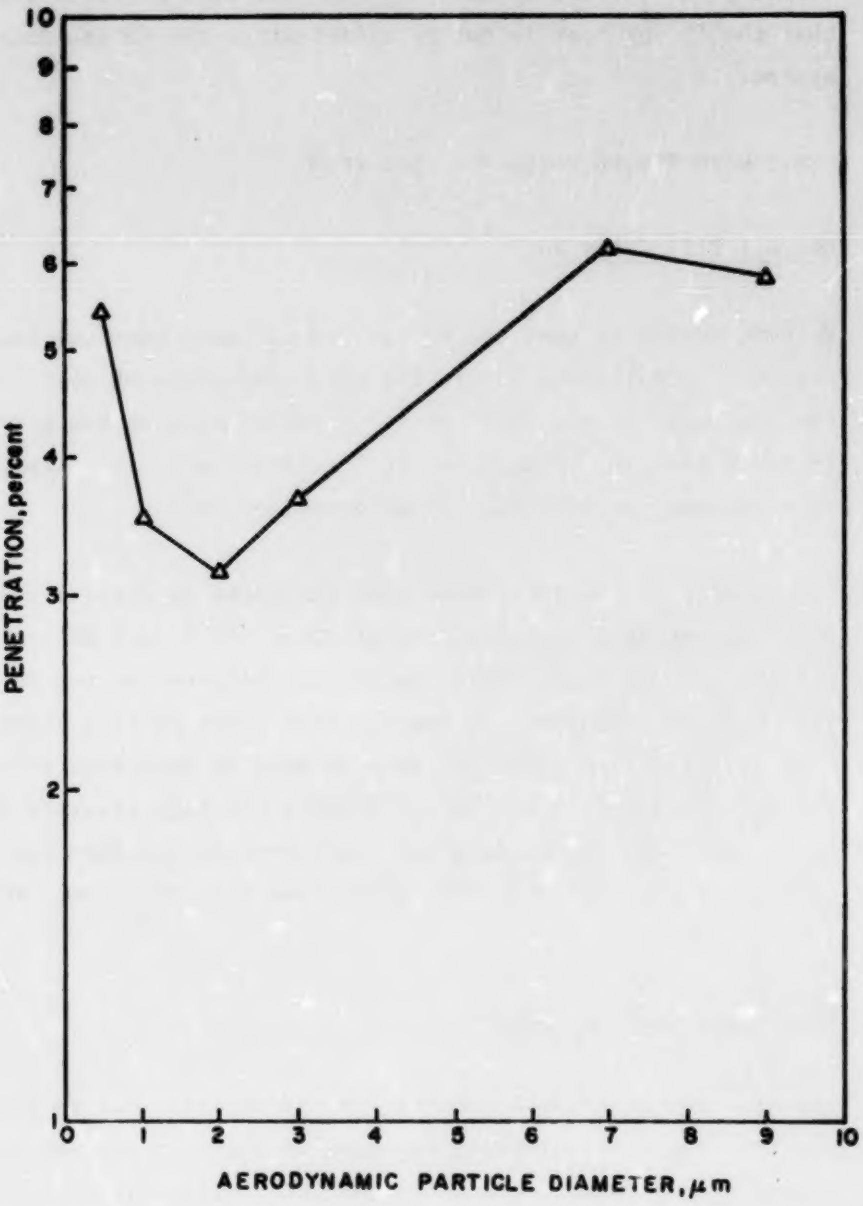

Figure 13. Penetration versus particle size for the 80 pores per inch foam

Figure 14 contains the 2 fractional penetration curves for the 65 ppi foam and the 80 ppi foam at nearly the same pressure drop. Since the face velocity was not the same for any runs with either foam, the similar pressure drop is the best remaining common parameter for comparison. It can be seen that the penetration is lower between 1 micron and 4 microns for the 65 ppi foam while it tends to be higher for the below 1 micron and above 5 micron particles. The overall penetration and shape of the curves is somewhat similar while the penetration is lower for the 80 ppi foam, perhaps due to the disproportionately higher mass of the larger particles which penetrated the 65 ppi foam.

RESULTS OF MEASUREMENTS WITH AN OPTICAL PARTICLE COUNTER AND A CONDENSATION NUCLEI COUNTER

As previously indicated in the test plan, we made both optical particle counter measurements and condensation nuclei counter measurements of some runs. These measurements were made for four of the five runs indicated in the test plan, since we were unable to make the CHEAF operate at condition 1322 long enough to make the measurements.

Both types of measurement yielded data in terms of number of particles equal to or greater than a given size, per volume. Therefore, the data had to be reduced to number of particles between a given size interval, and this number of particles was assigned to the geometric mean particle diameter of that interval. In this manner we were able to compare the number of particles assigned to a geometric mean particle diameter of the inlet and outlet of the CHEAF from which we calculated the penetration. As with our other calculations, we also corrected the outlet for the effects of air leakage at the CHEAF outlet. The data for these runs are given in Appendices D and E.

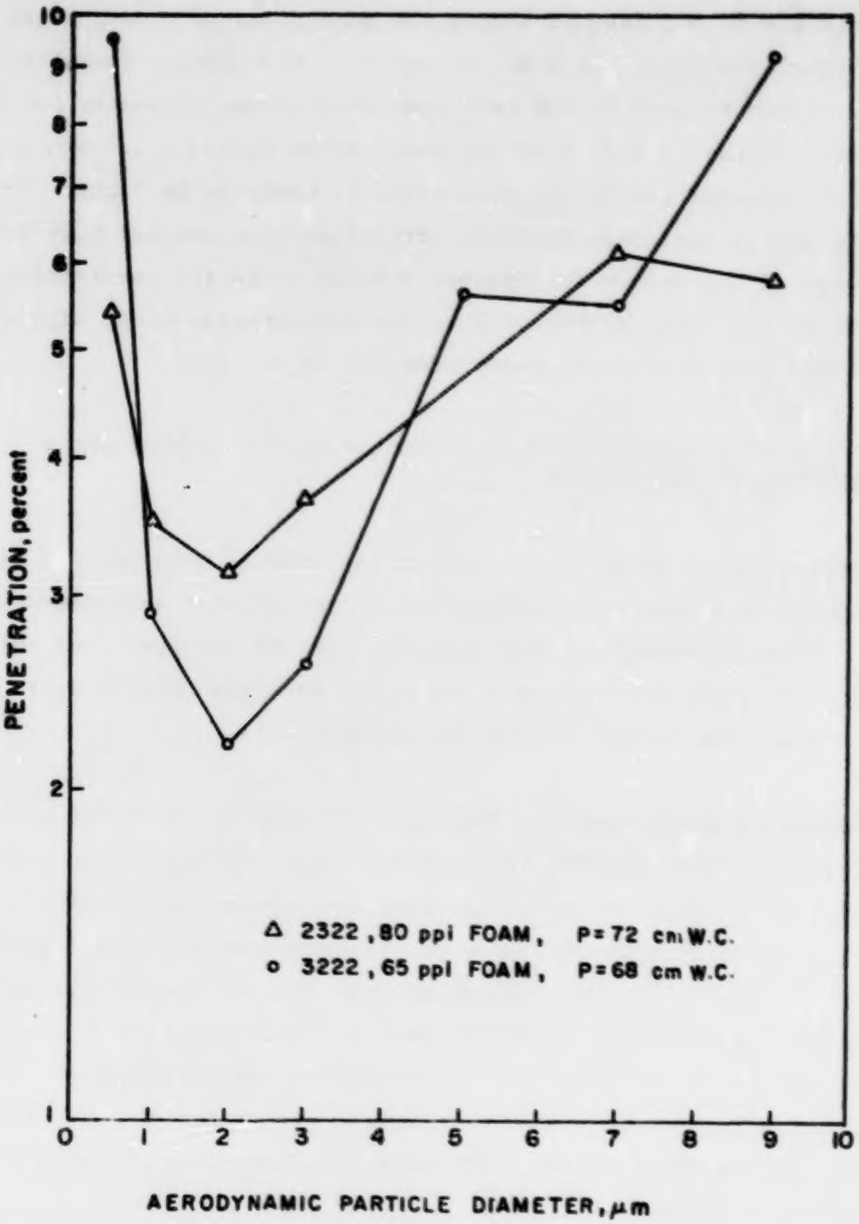

Figure 14. Penetration versus particle size for 80 ppi and 65 ppi foam at approximately the same pressure drop

Tests With the 65 Pores Per Inch Foam

The data from the optical particle counter and the condensation nuclei counter were combined to yield penetration versus particle size data from 1.4 microns down to 0.006 microns. The results for run 3222 are plotted in Figure 15 along with the penetration versus particle size curve for the impactor runs. The results are in good agreement with the impactor data, where they overlap. The points which go beyond the lower limits of the impactor data indicate a rapid rise in penetration with decreasing particle size which is as expected for particle impaction.

Similar tests for the lowest face velocity run 1222, given in Figure 16, indicate similar behavior for submicron particles. However, there is substantial disagreement between the impactor and optical counter data for the two points near 1 micron. Recall that the 1222 impactor data seemed anomalous (Figure 8).

Figures 15, 16, 18, and 19 were plotted with a linear scale for the particle size to facilitate their comparison with the preceding figures of penetration versus particle size. However, since the very fine particle size data is difficult to plot accurately on a linear scale, we have plotted Figure 17, the nominal conditions run (3222), with a log scale for geometric particle size. Here we can see more clearly that the penetration rises steeply below the 1 micron particle size, as would be expected from the penetration theory given below.

Tests With the 45 Pores Per Inch Foam

Figures 18 and 19 are very similar in nature to those for the 65 ppi foam just discussed. The submicron particles show the expected dramatic rise in penetration while the overlapping impactor data are in good agreement for the highest face velocity run and in poor agreement for the lowest face velocity run. Again we can offer no good explanation for these anomolous results near the 1 micron size.

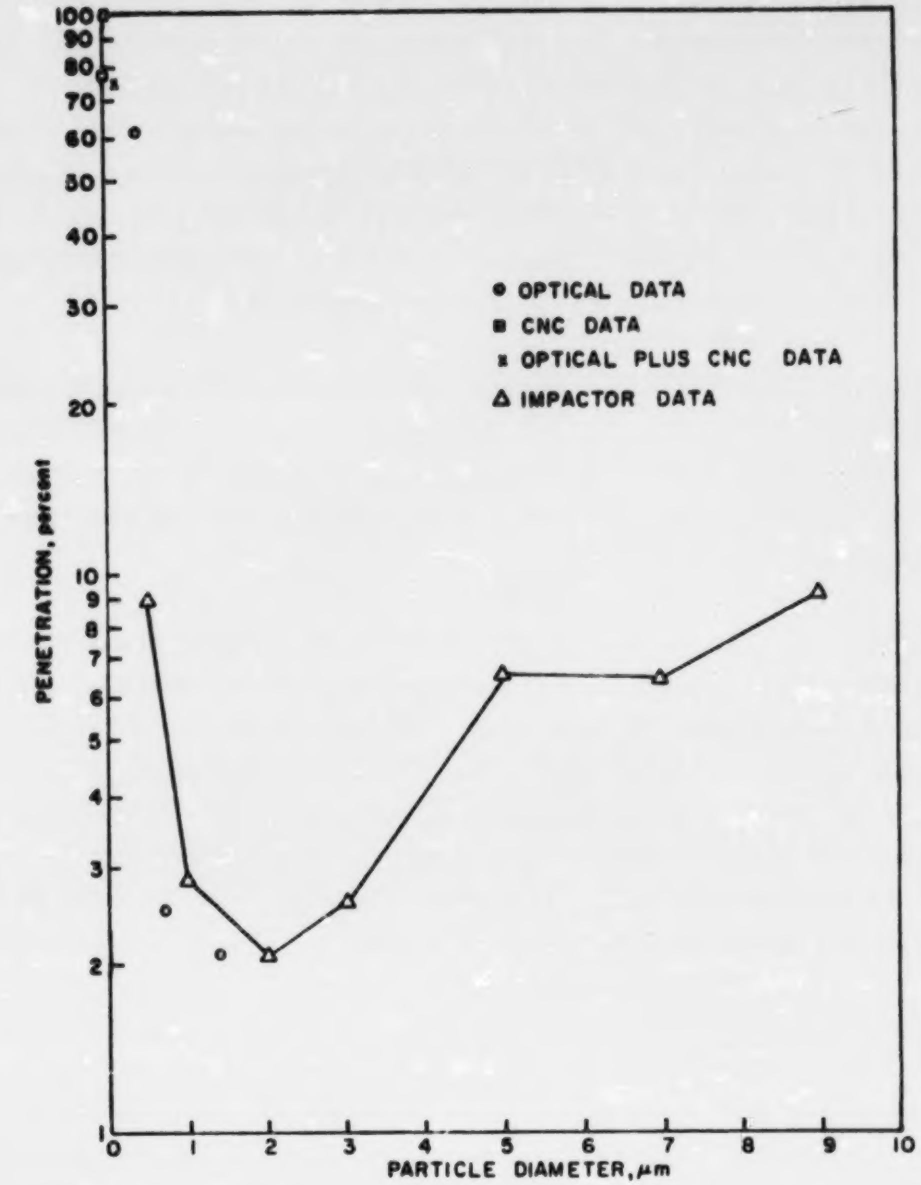

Figure 15. Penetration versus particle size for the 65 ppi foam at nominal conditions

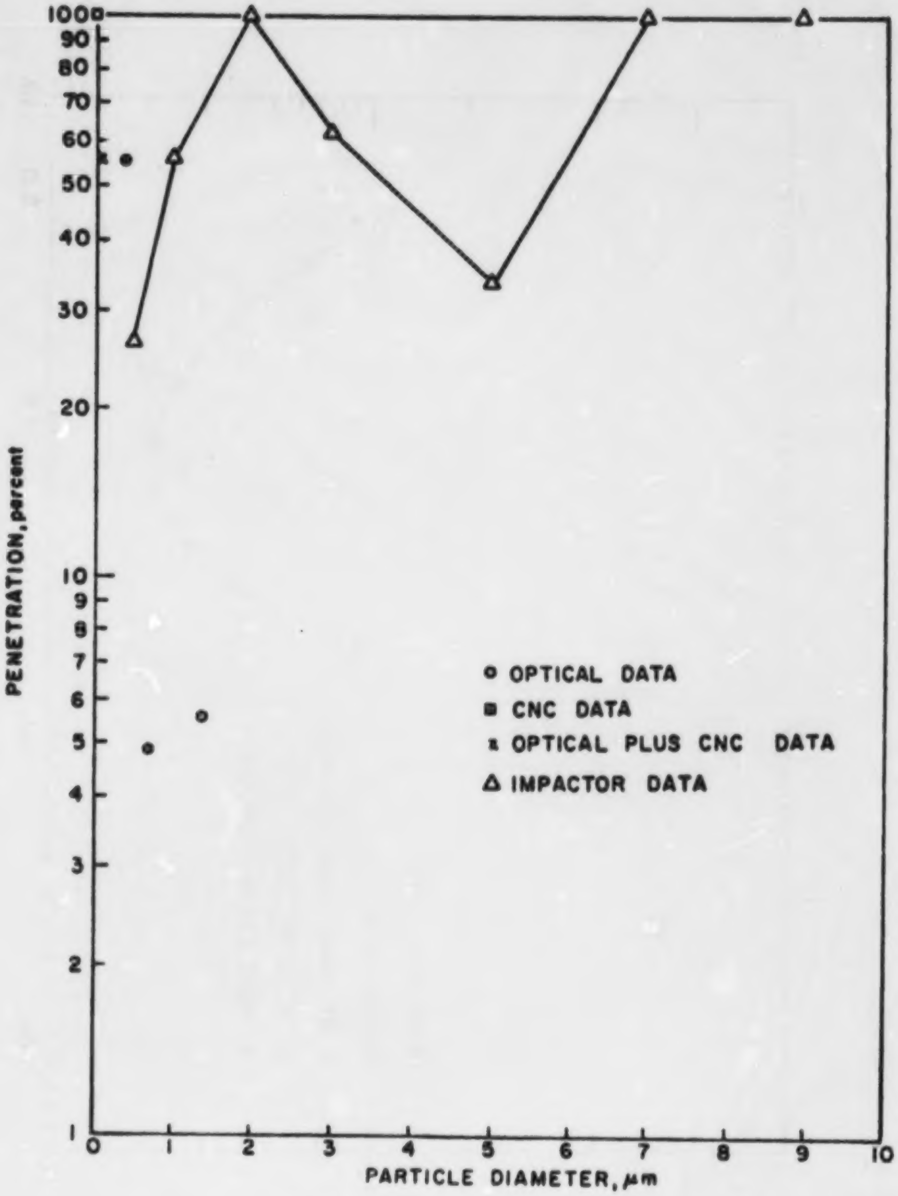

Figure 16. Penetration versus particle size for the 65 ppi foam at the lowest face velocity (1222)

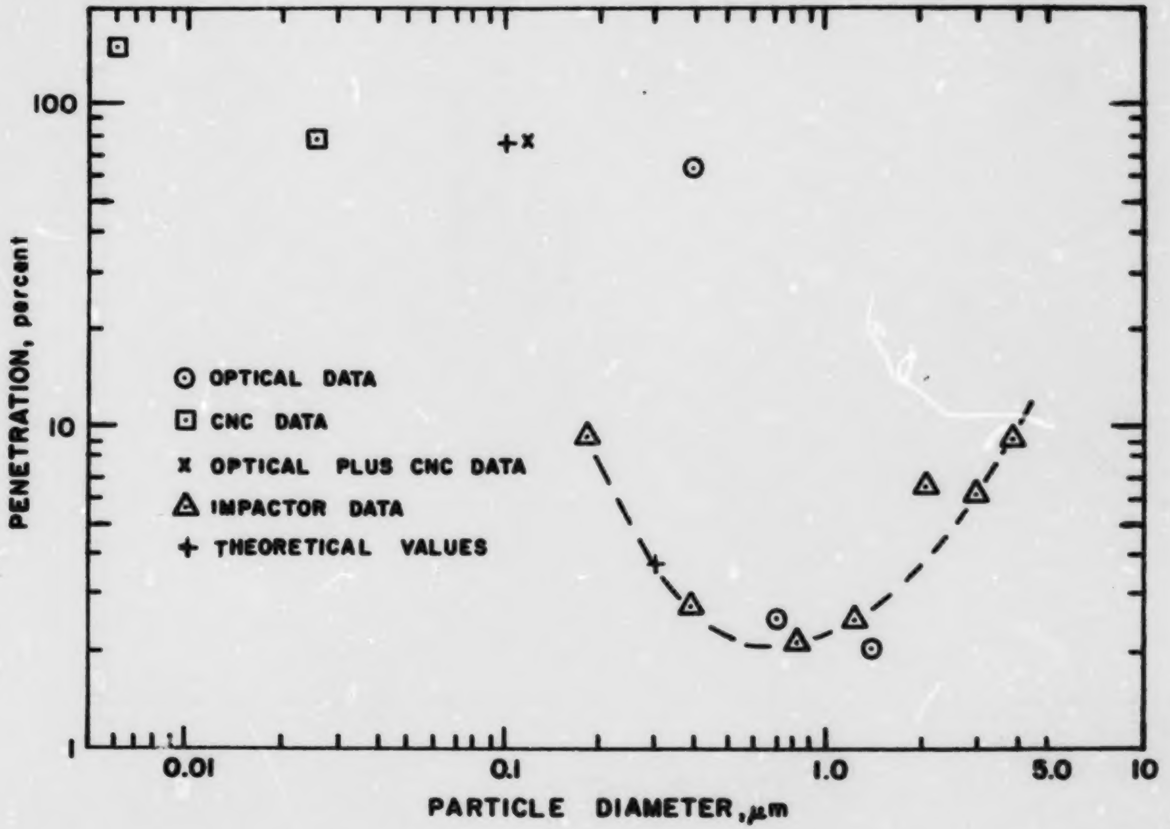

Figure 17. Penetration versus particle diameter for the 65 ppi foam at nominal conditions

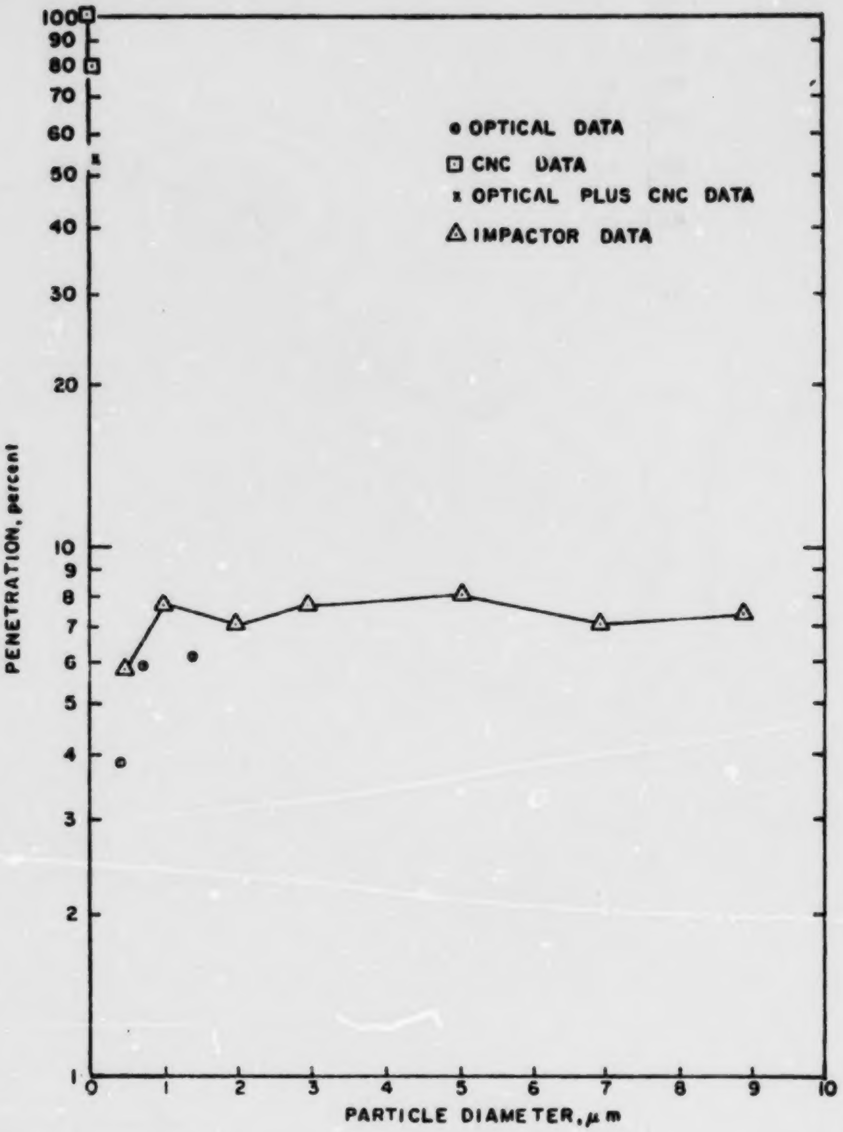

Figure 18. Penetration versus particle size for the 45 ppi foam at nominal conditions (2122)

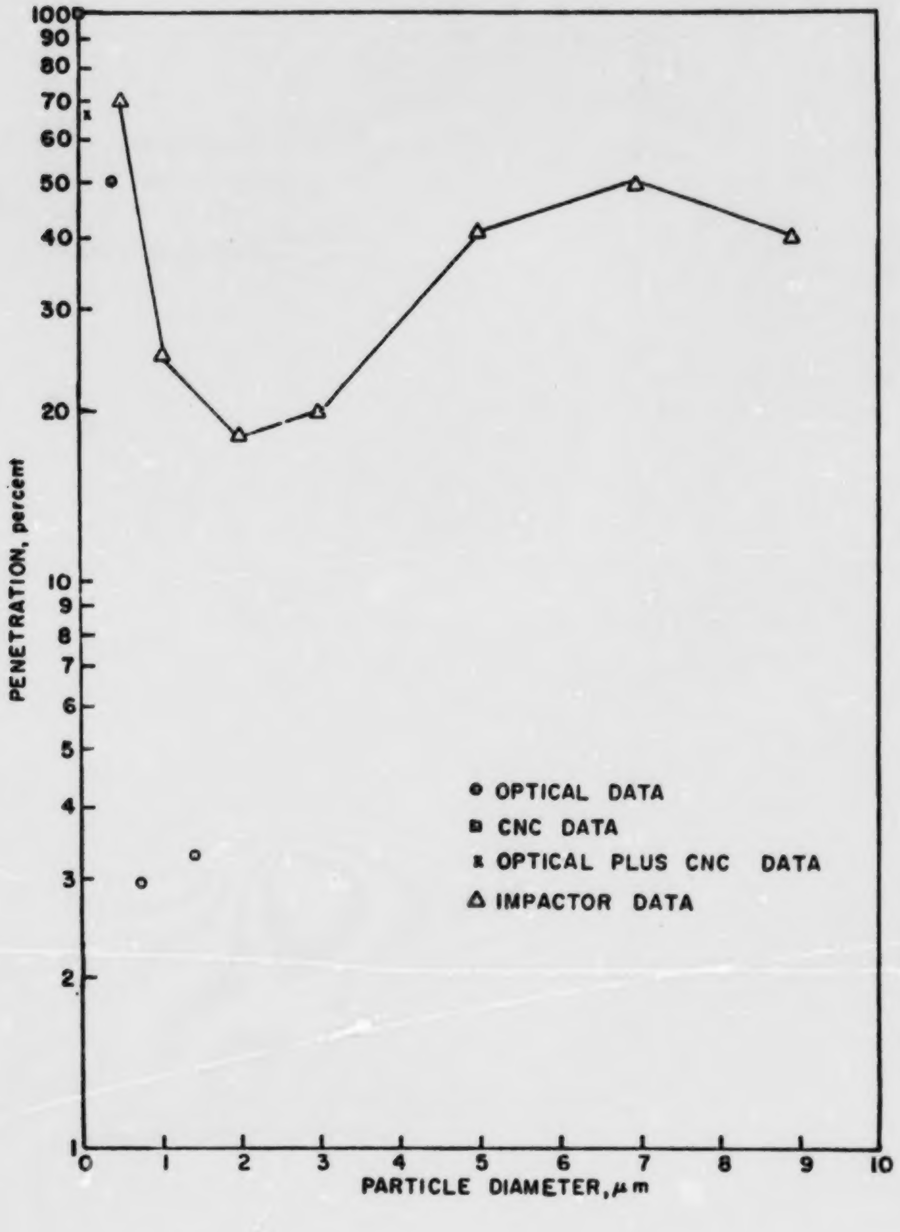

Figure 19. Penetration versus particle size for the 45 ppi foam at the lowest face velocity (1122)

TESTS WITH METAL FOAM

Overall Efficiency Run

The metal foam supplied by Andersen 2000, Inc. was made by plating the 45 ppi foam with nickel and burning out the polymer, leaving the structure with some 60 pores per inch, similar to the foam utilized for our nominal conditions. In all, four runs were made with the metal foam: two impactor runs, and two total mass runs. Each of the runs were at nominal conditions, similar to the 3222 series of runs. The most notable differences between the metal and urethane foam was the much smaller pressure drop across the metal foam (38 cm or 15 in. WC) at the nominal face velocity.

The two total mass efficiency runs yielded penetrations of 13.7 percent and 16.1 percent considerably higher than for the polyurethane foam of approximately the same pore structure, namely, the 65 pores per inch foam. The penetration versus pressure drop is more consistent with what we have observed from Figure 8; we estimate the 65 ppi foam would have had about 10 percent penetration at 38 cm WC.

Fractional Efficiency Run

The fractional penetration is plotted in Figure 20 from the average penetrations determined by the two impactor runs. The higher penetration may mask the effect of spray carryover, as there is no sign here of penetration increasing with particle size as it did in the more efficient case, the polyurethane foam.

STATISTICAL ANALYSIS: FLOW RATE, FOAM, MEASUREMENT ERROR

The data from the efficiency tests were subjected to a two-way analysis of variance, using a standard program, "BMD02V-Analysis of Variance for Factorial Design" (Revised 12 September 1969, UCLA Health Services Computing Facility). Such a two-way analysis works as follows:[3]

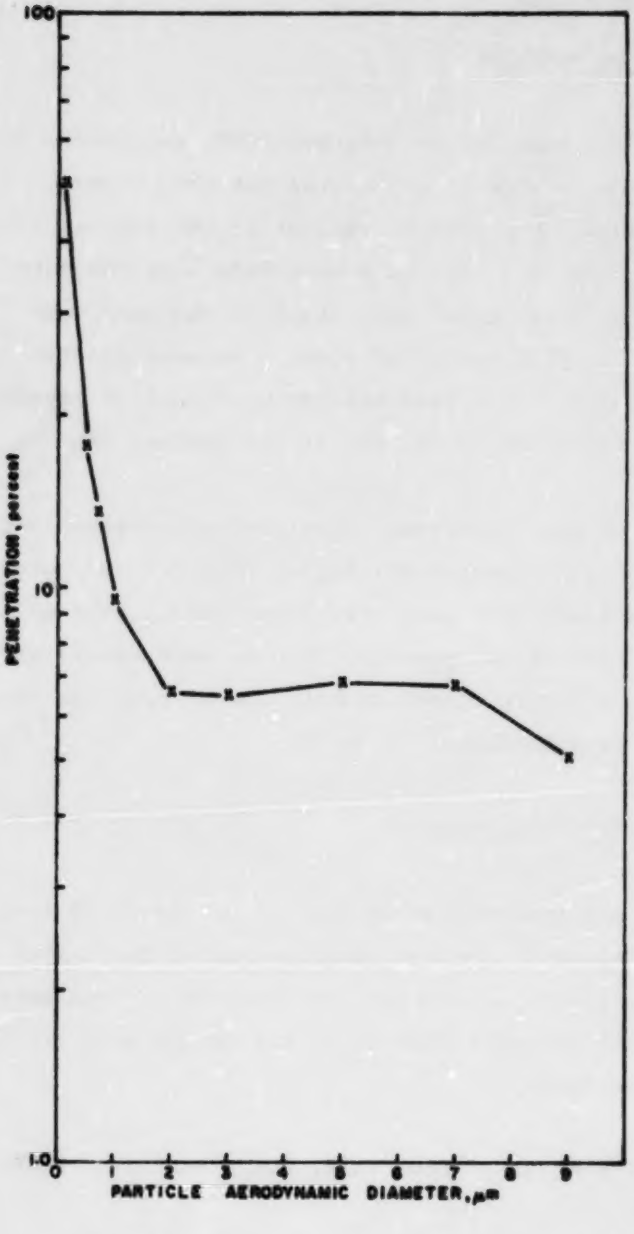

Figure 20. Penetration versus particle size with metal foam

1. The two factors (flow and foam) are arranged in a row and column format with r rows and c columns (here, $r = 3$ levels of flow and $c = 2$ foams).

2. It is assumed that each measurement value, x_{ij}, comes from the mean value μ, as altered by a row (flow) effect, α_i, and a column (foam) effect, β_j, and experimental error, e_{ij}, with e_{ij} assumed to be "independently and normally distributed with mean zero and common variance σ_o^2." That is:

$$x_{ij} = \mu + \alpha_i + \beta_j + e_{ij}.$$

$$\sum_i \alpha_i = \sum_j \beta_j = 0$$

3. The mean squares (sum of squares divided by degrees of freedom) for the rows and columns are divided by the residual mean square to form the F ratio.

4. This ratio is compared with the F value from tables; the F chosen is $F_p\left((r-1),\ (r-1)(c-1)\right)$ for the row comparison and $F_p\left((c-1),\ (r-1)(c-1)\right)$ for the column comparison, with p being the level of statistical significance (i.e., $p = 90$ percent means that ratios as large as $F_{90\%}$ would happen by chance only 10 percent of the time). From Table 5 of Crow, et al.[3] ($r = 3$, $c = 2$):

   $$F_{90}\ (2,\ 2) = 9.00$$

   $$F_{90}\ (1,\ 2) = 8.63$$

   $$F_{95}\ (2,\ 2) = 19.00$$

   $$F_{95}\ (1,\ 2) = 18.51$$

   Note that F (1, 2) means the F ratio for a variable with 1 degree of freedom (foam pore density) versus one with 2 (residual).

Table 9 shows the results of such an analysis. The first column has the aerosol size fraction; the second has the mean of all efficiency tests for that size; the third through fifth give the mean efficiencies for that size

Table 9. GRAND MEAN, MARGINAL MEANS, AND ELEMENTS OF THE ANALYSIS OF VARIANCE FOR EFFICIENCIES AT DIFFERENT PARTICLE SIZES, GAS FLOWS, FOAM PORE DENSITIES

No.		Grand mean	Marginal means						Source of variation	Degree of freedom	Mean squares	F ratio	Significance
			Flow			Foam pore density							
			250	500	800	45	65	80					
1.	Total	82.897	68.015	88.175	92.500	77.140	88.650	—	Flow	2	342	12.34	> 0.90
									Foam density	1	199	7.21	—
									Residual	2	27.6		
									Total	5			
2.	Total	84.038	77.183	90.893	—	70.515	85.675	95.925	Flow	1	282	4.02	—
									Foam density	2	327	4.67	—
									Residual	2	70.0		
									Total	5			
3.	9 μm	69.950	29.730	88.445	91.675	80.083	59.817	—	Flow	2	2,431	4.22	—
									Foam density	1	616	1.07	—
									Residual	2	577		
									Total	5			
4.	7 μm	68.175	25.000	86.435	93.090	76.183	60.167	—	Flow	2	2,818	6.51	—
									Foam density	1	385	0.89	—
									Residual	2	433		
									Total	5			
5.	5 μm	81.780	62.335	88.500	94.505	78.223	85.337	—	Flow	2	585	518	> 0.995
									Foam density	1	75.9	67.2	> 0.975
									Residual	2	1.13		
									Total	5			
6.	3 μm	81.975	59.135	92.010	94.780	86.783	77.167	—	Flow	2	786	1.94	—
									Foam density	1	139	0.34	—
									Residual	2	406		
									Total	5			
7.	1 μm	80.913	59.165	88.895	94.680	84.947	76.880	—	Flow	2	726	3.47	—
									Foam density	1	97.6	0.466	—
									Residual	2	210		
									Total	5			
8.	0.5 μm	77.808	51.895	89.235	92.295	70.467	85.150	—	Flow	2	1,012	3.17	—
									Foam density	1	323	1.01	—
									Residual	2	319		
									Total	5			

at different flows; the sixth through seventh (and in one case eighth) columns give the mean efficiencies for different foams for that fraction. Finally, the ninth through thirteenth columns give the values and results in connection with the statistical analysis.

From the analysis we conclude:

1. Although it is evident that increasing the flow increased efficiency in every case, this was demonstrated statistically significant ($p \geq 90$ percent) only for the total collection efficiency and for the 5 μm particle size aerosol fraction.
2. Higher foam densities (pores per inch) sometimes produced improved collection efficiency and sometimes did not, with a statistically significant improvement demonstrated only for the 5 μm size. (This lack of demonstrable improvement is puzzling. Explanations might be that improved particle capture is being offset by increased particle release in the finer foam or that capture is nearly complete for both and release is similar for both.)

The two-factor model assumes that the variation due to flow is independent of that from foam density and vice-versa. All effects other than the row (flow) and column (foam) are included in the residual e_{ij} (thus in σ_o). Table 10 has listed the root mean square (RMS) residuals, which are estimates of σ_o, sometimes (loosely) called the experimental error. The values of σ_o for 5 μm, 1 μm, and 0.5 μm are quite like those for very similar tests done by GCA in evaluating the Dynactor scrubber (Cooper and Anderson, 1975);[2] for 3 μm, the 20 percent is much larger than the (approximately) 1 percent for the Dynactor tests and the values for the total filter tests are much larger than the 1.3 percent value for such tests in the Dynactor study. These figures indicate there were other sources of variation (beyond flow and foam) for the CHEAF evaluation, but that the sources of variation might well not be "experimental error," as they were often much larger than the "experimental error" of the Dynactor.

Table 10. ROOT MEAN SQUARE RESIDUALS ESTIMATES OF σ_o AND REPLICATION ESTIMATE OF σ

Aerosol aerodynamic diameter fraction	Root mean square residuals, σ_o	Measurement error estimate from four replicate runs	
Total 1[b]	5.3%	Range (w)	$\sigma = (0.49)$ w[a]
Total 2[c]	8.4%	0.9[d]	0.44
9 μm	24.0%	7.6	3.7
7 μm	20.8	6.6	3.2
5 μm	1.1	4.9	2.4
3 μm	20.1	1.9	0.93
1 μm	14.5	1.7	0.83
0.5 μm	17.7	11.5	5.6

[a] Best estimate of σ_o from range of four measurements.[5]

[b] Three flows times two foam densities, total filter values.

[c] Three foam densities times two flows, total filter values.

[d] Total filter results for the four replicate runs.

Table 10 also has an error estimate from the four replicate tests made at nominal CHEAF operating conditions. The estimates of experimental error, σ, from the replicate runs are (except at 5 μm) much smaller than the RMS residuals from the factorial tests. This is strong evidence for concluding that the simple model

$$x_{ij} = \mu + \alpha_i + \beta_j + e_{ij}$$

does not account for all the effects of flow rate and foam density. A more detailed statistical test model would take into account the interactions of flow and foam (as done for the Dynactor evaluation)— for example the degree to which the difference between high and low flow velocities is different for the various foams.

In Table 11, we have listed for the CHEAF at normal operating conditions the mean efficiencies and the standard deviation of the means ($\sigma_{\bar{x}} = \sigma_0/\sqrt{N}$), the latter derived from the last column in Table 10. These results are in general agreement with those of Calvert, Rowan, and Lake,[6] who found efficiencies in the range 91 to 96 percent for particle dry aerodynamic diameters from 0.5 µm to 2.0 µm (nearly independent of particle size) for a CHEAF installation on a diatomaceous earth calcining and drying process operating at ~ 50 cm WC (20 in. H_2O) and 0.11×10^{-3} m^3 water per m^3 gas.

Table 11. SUMMARY OF MEAN PERCENTAGE EFFICIENCIES AND STANDARD DEVIATION OF THESE MEANS FOR THE CHEAF UNDER THE NORMAL OPERATING CONDITIONS (TEST SERIES 3222)

Aerosol aerodynamic diameter fraction	Mean efficiency, percent	Estimated standard derivation of the mean, percent	Mean penetration, percent
Total[a]	94.6	0.2	5.4
9 µm	90.8	1.9	9.2
7 µm	93.5	1.6	6.5
5 µm	93.4	1.2	6.6
3 µm	97.4	0.5	2.6
1 µm	97.1	0.4	2.9
0.5 µm	90.4	2.8	9.6

[a] Total efficiency for iron oxide aerosol at normal conditions.

POWER CONSUMPTION

The power used by a scrubber is predominantly the pressure drop of the air going through the scrubber (Δp) times the flow rate of the air (Q_g) in actual volume terms divided by the fan/motor power efficiency.

We measured the pressure drop across the fan in the CHEAF unit using a Magnehelic.™ For the 65 pores per inch foam at nominal conditions the pressure drop across the entire CHEAF, including ducting, cyclone, drum, and demisters, was 1.5 cm, 5 cm, 68 cm, and 5.5 cm, respectively, for a total of 80 cm (31.5 inches) WC. The gas flow at the fan inlet was measured to be approximately 0.47 am^3/s (1000 acfm). Thus the power consumption of the CHEAF is the pressure drop in N/m^2 times the actual volume flow in m^3/s, or:

$$
\begin{aligned}
\text{Power} &= Q_g \, \Delta P \\
&= (0.47 \text{ m}^3/\text{s}) \, (7.85 \times 10^3 \text{ N/m}^2) \\
&= 3.7 \text{ kW}
\end{aligned}
$$

This gives the air power consumption in kilowatts. A good estimate of the electrical power consumption is to assume motor plus fan efficiency of 0.6. Using this assumption we get an overall electrical power consumption of 13.1 $kW/m^3/s$ (8.3 HP/1000 acfm). The CHEAF fan motor was rated at 10 horsepower; therefore, it is in reasonably good agreement with our estimate.

The CHEAF also used pumps for water sprays and a very small motor to turn the filter drum. The combined power rating of these three motors was under 746 watts (1 horsepower).

Comparison of CHEAF with Other Scrubbers

One method of comparison between the performance of various particulate control devices with regard to their power consumption is to compare their energy consumptions for given aerodynamic cut diameters, as presented in Figure 21. Aerodynamic cut diameter is the aerodynamic diameter for which collection efficiency is 50 percent. Pressure drop is equivalent to air power used per volume flow rate and it serves as a useful measure of power consumption per flow capacity for different devices (we have not included for the CHEAF the small pump power consumption).

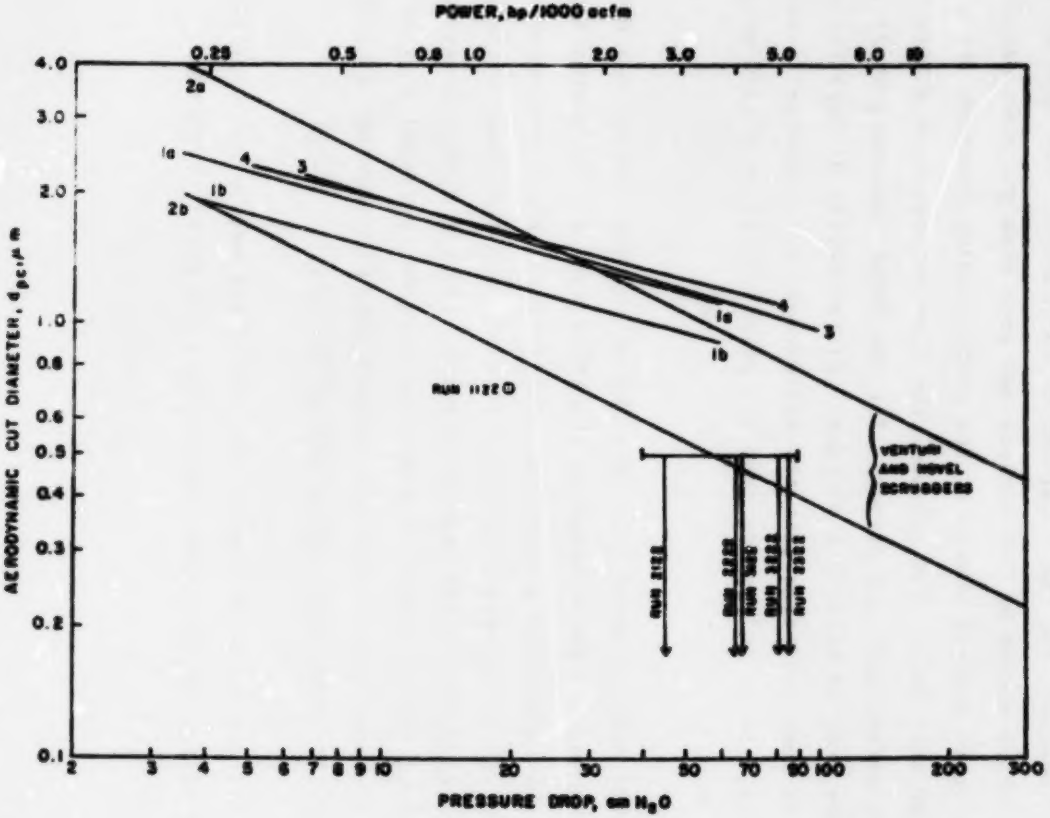

Figure 21. Predicted aerodynamic cut diameter versus pressure drop and power consumption (adapted from Scrubber Handbook). Lines 1a and 1b are for sieve plates; line 3 is for impingement plate; line 4 is for a packed column; lines 2a and 2b are for venturi scrubbers with f = 0.25, 0.50 respectively. See text

The last size interval we obtained using the impactors was 0 to 0.5 μm. Since the aerodynamic cut diameter for the CHEAF occurred at greater than one-half micron for only one condition, we were only able to plot one point. However, for the remainder of the runs we were able to indicate a line which starts at 0.5 microns and goes straight down parallel to the y-axis which defines where, at the corresponding pressure drop, the cut diameter must fall. For example, the line for run 2122 should be read as, the aerodynamic cut diameter for the CHEAF operating at 28 cm H_2O pressure drop is below 0.5 microns. Extrapolation of impactor data for the 3222 runs indicates that the aerodynamic cut diameter is much less than 0.5 micron, indicating that the point should be placed very low on the line.

It should also be noted here that the use of the cyclone may have detracted from the overall performance of the CHEAF per unit of energy expended. Because we generated a very fine test aerosol, the low-pressure-drop cyclone would not have been very efficient and the CHEAF might have yielded essentially the same penetration for our fine test aerosol with or without the cyclone. However, the cyclone contained a water spray which may have conditioned the aerosol somewhat previous to seaching the foam-filter drum, which would aid collection.

It is evident from the figure that the CHEAF may be substantially more energy efficient than many conventional and novel scrubbers.

SECTION VI

THEORETICAL PREDICTION OF EFFICIENCIES

The pore structure of the CHEAF collection material was modeled as an array of equally spaced cylinders intersecting each other and parallel to the x, y, or z axis, a "jungle gym" configuration (see Figure 22).

The void volume fraction of the material is $\epsilon = 0.97$.[7] To determine fiber diameter, consider a volume LxLxL in dimension (see Figure 22). Each face, front, side, top, has $(L\ \ell)^2$ rods (fibers) perpendicular to it (ℓ is number of pores per length) so the total number of fibers is $N_f = 3(\ell\ L)^2$. The volume is L^3 and the fraction of that which is solid is $(1-\epsilon)$. The solid volume is just that of the fibers: $(1-\epsilon)L^3 = 3(\ell\ L)^2\ (\pi/4)d_f{}^2L$. The fiber diameter is thus $d_f = \left[4(1-\epsilon)/3\pi\right]^{1/2}/\ell$. Using ℓ not in pores per inch but in pores per cm, one obtains fiber diameters 64 μm, 44 μm, 36 μm for 45, 65, 85 ppi foam.

A first approximation to the open face area in a layer is just L x L minus the area of fibers parallel to the face. The fractional open area becomes

$$\left| L \times L - \left[2\ (L\ \ell)\ (Ld_f) - (L\ \ell)^2\ (d_f)^2 \right] \right| / L \times L$$

where the last term in brackets comes from discounting overlapping. The open fraction is thus

$$1 - 2\ (\ell\ d_f) + (\ell\ d_f)^2$$

and we can obtain $(\ell\ d_f)$ from the equation for d_f above:

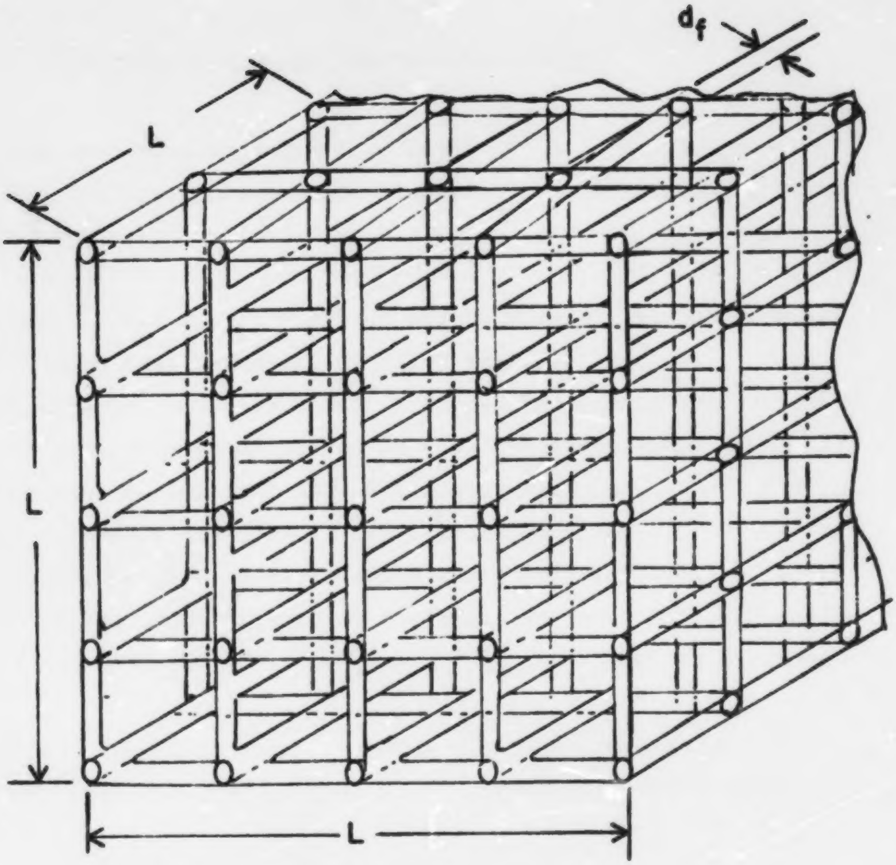

Figure 22. Schematic of jungle gym model of porous foam

$$\ell\, d_f = \left[4(1 - \varepsilon)/3\pi\right]^{1/2}$$

$$= 0.113 \quad \text{for } \varepsilon = 0.97$$

So the fractional open area of each layer is 0.787, and the fractional fiber area is 0.214. (The values used in the calculation below were 0.78 and 0.22, respectively.)

1. Diffusion (from Stafford and Ettinger,[8] after Stairmand)

$$\eta_D = (8D/v_o\, d_f)^{1/2}$$

where η_D = single fiber efficiency due to diffusive collection

D = particle diffusivity, cm^2/s

v_o = foam face velocity, cm/s

d_f = fiber diameter, cm

2. Interception[9]

$$\eta_C = 1+R-(1+R)^{-1} \doteq 2R$$

where η_C = single fiber efficiency due to interception

R = ratio of particle diameter to fiber diameter, d_p/d_f

3. Impaction (curve fit to data of May and Clifford)[10]

$$\eta_I = \psi^2/(\psi^2 + 0.64)$$

where ψ = impaction parameter

$\psi = C\rho_p\, d_p^{\,2}\, v_o/18\, \mu\, d_f$

where C = Cunningham correction factor $(1+0.16\ \mu m/d_p)$

ρ_p = particle density, g/cm^3

μ = gas viscosity, poise.

4. **Combined efficiencies, assumed independent**

$$\eta = 1-(1-\eta_I)(1-\eta_C)(1-\eta_D)$$

Efficiency of a single layer was calculated from

$$\eta_L = 0.22\ \eta,$$

the fractional area of fibers in a layer times the efficiency of a fiber. Efficiency of the whole foam (1-inch thick) was calculated from

$$E = 1-(1-\eta_L)^N$$

one minus the probability that a particle would escape capture N times.

where N = pores per inch times thickness in inches.

Table 12 gives the results of these calculations. Figures 23 and 24 show the penetrations as a function of particle diameter (assuming $\rho_p = 1\ g/cm^3$). These results are derived from a model which assumes all particles which strike the (wet) surface are caught (probably nearly true) and none are reentrained (not true). The following trends are apparent for the cases studied:

a. Penetration decreased as particle size increased, for $d_p \gtrsim 0.3\ \mu m$.

b. Penetration decreased as velocity increased, for $d_p \gtrsim 0.3\ \mu m$.

c. Penetration decreased as pore grade (pores per inch) increased, for a given thickness of foam.

d. At 1000 cm/s, impaction was the dominant mechanism for particles $d_p \gtrsim 1\ \mu m$. At 100 cm/s, impaction dominated for $d_p \gtrsim 3\ \mu m$.

e. Interception was nearly as important as or more important than impaction for $d_p = 0.3\ \mu m$, and diffusion was negligible. Interception was also significant for $d_p = 1\ \mu m$, especially at the lower flow velocity.

Table 12. PREDICTED PENETRATIONS UNDER ASSUMPTIONS NOTED IN TEXT

PORE GRADE (PORES PER INCH)	FACE VELOCITY (CM/SEC)	PARTICLE DIAMETER (MICRONS)	SINGLE FIBER EFFICIENCIES			TOTAL EFFICIENCY	PENETRATION
			INTERCEPTION	DIFFUSION	IMPACTION		
45.							
	100.						
		0.1	0.0032	0.0093	0.0001	0.1147	0.8854
		0.3	0.0095	0.0040	0.0001	0.1239	0.8762
		1.0	0.0315	0.0019	0.0049	0.3131	0.6870
		3.0	0.0943	0.0011	0.2460	0.9613	0.0388
		10.0	0.3141	0.0006	0.9740	1.0000	0.0001
	1000.						
		0.1	0.0032	0.0030	0.0003	0.0602	0.9399
		0.3	0.0095	0.0013	0.0069	0.1584	0.8417
		1.0	0.0315	0.0006	0.3281	0.9724	0.0277
		3.0	0.0943	0.0004	0.9703	1.0000	0.0001
		10.0	0.3141	0.0002	0.9998	1.0000	0.0001
65.							
	100.						
		0.1	0.0046	0.0111	0.0001	0.1992	0.8009
		0.3	0.0137	0.0048	0.0002	0.2312	0.7689
		1.0	0.0454	0.0023	0.0101	0.5592	0.4409
		3.0	0.1361	0.0013	0.4050	0.9994	0.0007
		10.0	0.4536	0.0007	0.9874	1.0000	0.0001
	1000.						
		0.1	0.0046	0.0035	0.0006	0.1146	0.8855
		0.3	0.0137	0.0015	0.0143	0.3403	0.6598
		1.0	0.0454	0.0008	0.5047	0.9997	0.0004
		3.0	0.1361	0.0004	0.9856	1.0000	0.0001
		10.0	0.4536	0.0003	0.9999	1.0000	0.0001
80.							
	100.						
		0.1	0.0056	0.0123	0.0001	0.2687	0.7314
		0.3	0.0168	0.0053	0.0003	0.3221	0.6780
		1.0	0.0559	0.0025	0.0152	0.7225	0.2776
		3.0	0.1675	0.0014	0.5076	1.0000	0.0001
		10.0	0.5583	0.0008	0.9917	1.0000	0.0001
	1000.						
		0.1	0.0056	0.0039	0.0008	0.1642	0.8359
		0.3	0.0168	0.0017	0.0214	0.5002	0.4999
		1.0	0.0559	0.0008	0.6069	1.0000	0.0001
		3.0	0.1675	0.0005	0.9904	1.0000	0.0001
		10.0	0.5583	0.0003	1.0000	1.0000	0.0001

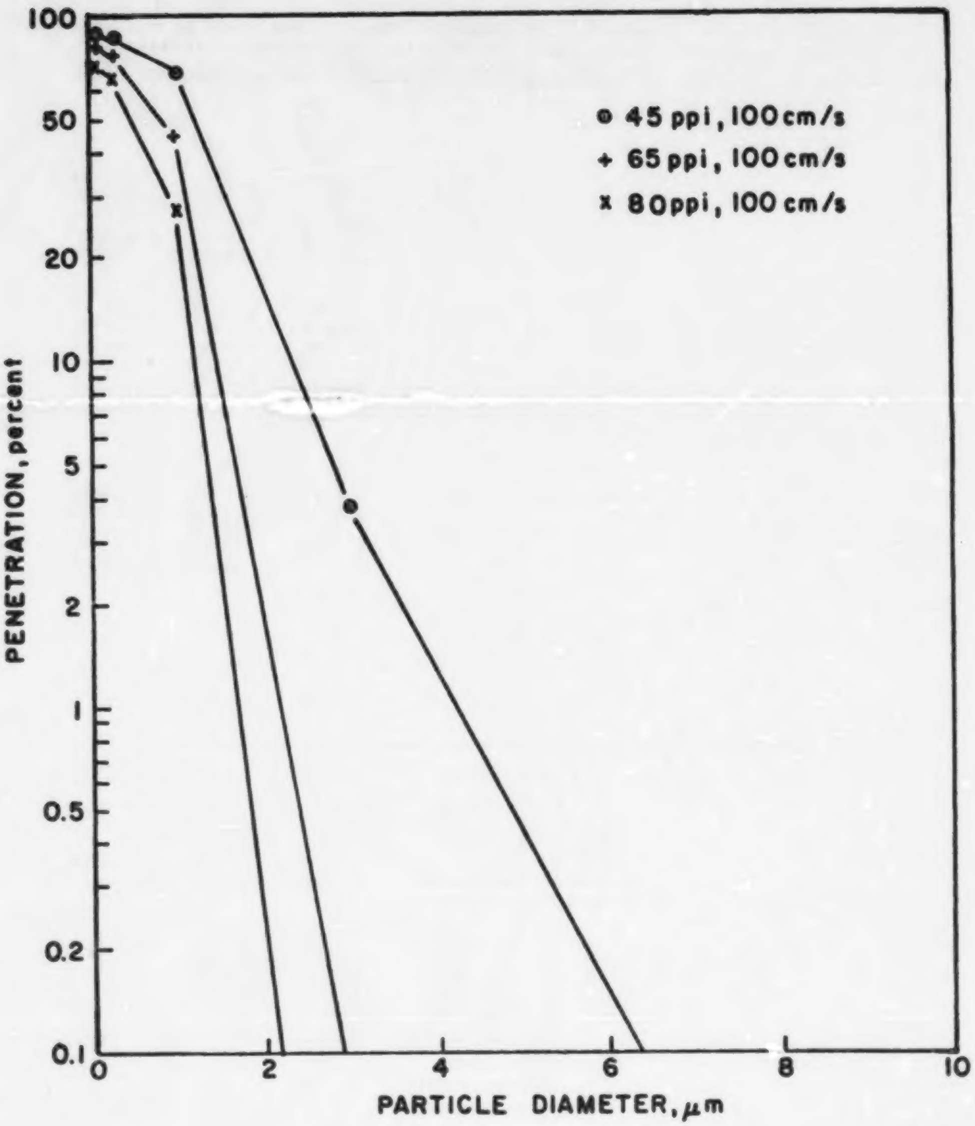

Figure 23. Predicted particle size versus penetration for three foam porosities at a low face velocity, 100 cm/s

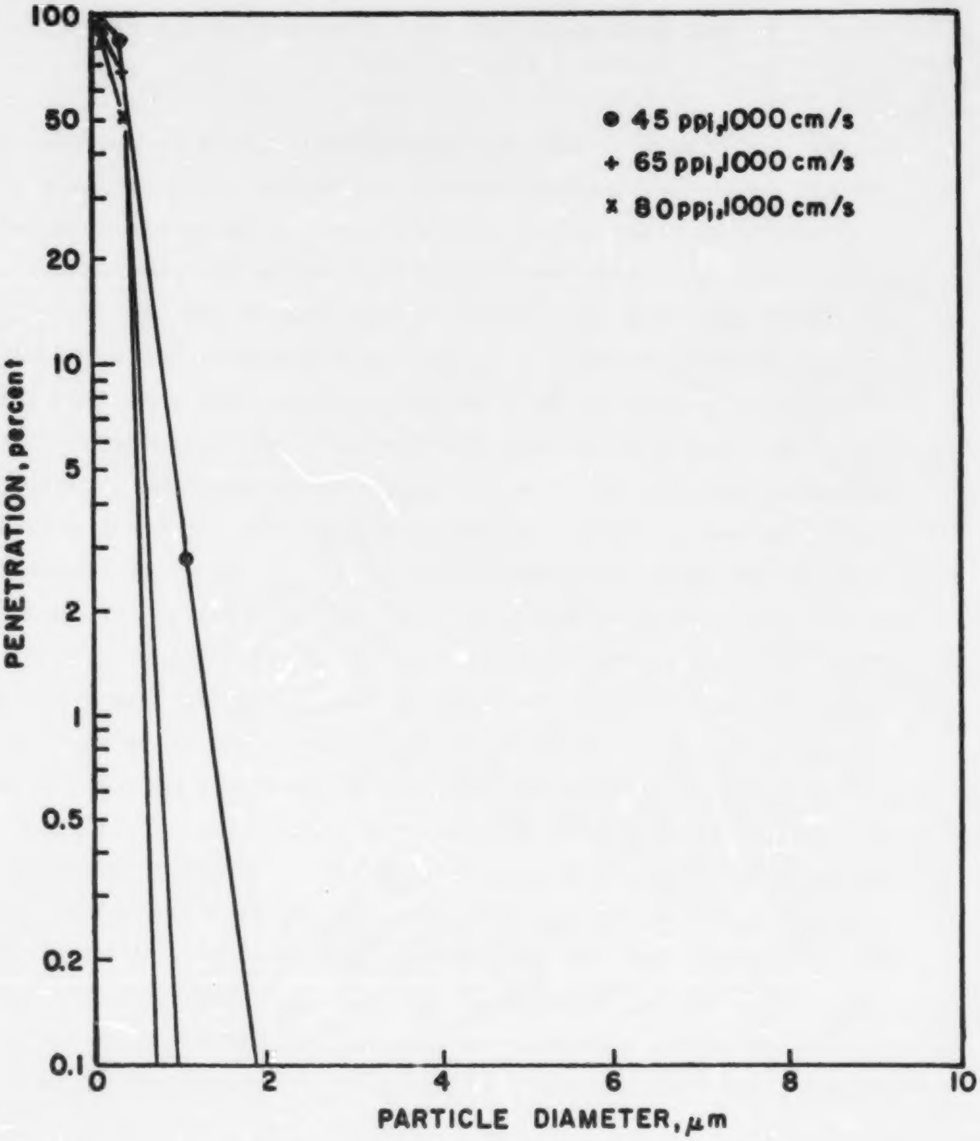

Figure 24. Predicted particle size versus penetration for three foam porosities at a high face velocity, 1000 cm/s

f. Diffusion was about as important as or more important than interception for particles ~ 0.1 μm and both were much greater than impaction.

g. At 1000 cm/s much less than 1 percent of all particles of $d_p \geq 3$ μm would penetrate.

Recall that Figure 17 had the experimental values of penetration at nominal conditions graphed against our estimates of particle diameter (converting impactor aerodynamic diameter to geometric diameter); the two crosses on that figure were obtained by doing the theoretical calculations described above for the case of 65 ppi foam at 800 cm/s face velocity for particles of density 5.2 g/cm^3 (iron oxide). For particles 1 μm in diameter or larger, the predicted penetrations were less than 10^{-4}, much lower than the observed penetrations (more evidence for the reentrainment explanation). At 0.3 μm the penetration was predicted to be 0.045, in nearly perfect (probably fortuitous) agreement with interpolation of the impactor measurements; at 0.1 μm geometric diameter, the predicted penetration was 0.78, again quite close to the measured value. Except for the optical counter data at 0.4 μm, the information shown in Figure 17 shows a consistent picture for particles less than about 1/2 μm: penetration increases from a few percent to nearly 100 percent as particle size goes from tenths of microns to hundredths. Interception is more important than diffusion even at 0.1 μm. If diffusion were becoming an important collection mechanism, we should expect a decrease in penetration as particles became much smaller than a few tenths microns, unless perhaps there is another source of particulate matter in this finest size range. The theory, which did not take into account reentrainment, agreed with the experimental results over the limited size range of several hundredths of a micron to several tenths of a micron.

SECTION VII

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APPENDIX A

MANUFACTURER'S DESCRIPTION OF CHEAF

ANDERSEN 2000 INC.

CHEAF AIR POLLUTION CONTROL EQUIPMENT

The Andersen 2000 Inc. Cleanable Media High Efficiency Air Filter (CHEAF) was introduced commercially to the air pollution control market in early 1975. The CHEAF system combines features of filtration equipment, wet scrubbers, and Brownian motion or diffusion controlled mist eliminators.

The CHEAF unit is mechanically simple, inherently reliable and is physically quite small in comparison with other fine particle emission control equipment. It can be built of any stainless steel alloy, mild steel, plastic, fiber glass, reinforced plastic, or rubber-lined steel.

The CHEAF system requires an extremely low liquid-to-gas ratio, possibly the lowest of any type of wet emission control equipment available today. This, of course, reduces the size of pumps, tanks, connecting piping, and other liquid handling equipment associated with the air pollution control installation.

The CHEAF system is well suited to the collection of submicron water soluble particulates and aerosols, including ammonium nitrate and urea prill tower emissions, soda and borosilicate glass furnace emissions, phosphoric acid mists and phosphorus pentoxide fumes, emissions from inorganic chemical calciners and dryers, food product spray dryers, galvanizing fumes and sulfuric acid mists. It is also well suited to control of insoluble particulate matter which has a mean diameter of less than 1.0 micron. This makes it an excellent control device for metallurgical fumes. The CHEAF system is not capable of handling large quantities of particulate matter exceeding 5 microns in diameter, although low energy pre-collectors can often be installed to remove these components prior to entry into the CHEAF system. The CHEAF system is normally considered for applications where high energy scrubbers or Brownian motion controlled mist eliminators might also be considered.

The CHEAF air pollution control system utilizes a porous urethane or metallic foam material as the filter medium. The foam is installed as a 1-inch thick mat over the perforated filtration drum. The foam is secured to the drum using screw clamps. The foam material can be removed and replaced in a very short time on the largest CHEAF unit.

The perforated drum, with the reticulated foam in place, is rotated in the CHEAF housing and is continuously wetted by spray nozzles mounted at locations around the drum housing. The sprays around the drum keep the pores of the foam lined with a film of liquid so that as particulate matter, aerosols, and fumes pass through the pores, they are contacted with the scrubbing solution and are either dissolved or are agglomerated and captured in liquid drops. Most of the gas stream contaminants pass through the pores in the filter material with the liquid. Particulate matter, which is larger than the pores, will deposit on the surface of the foam. In small concentrations, this material is cleaned from the surface by turbulent washing action from the sprays as the drum rotates past the nozzles. However, if the concentration of this large particulate matter (greater than 5 microns in diameter) exceeds about 0.10 grains/standard dry cubic foot, pluggage to the filter media will occur. A pre-collector should be used where this condition exists.

The foam filter media, which is supplied for the CHEAF unit, typically has 60 pores per linear inch. The velocity through the filter material is normally between 1,500 and 2,500 ft/min. This corresponds to a pressure drop across the CHEAF unit of between 10 and 30 inches W.G. The total liquid flow rate to the CHEAF unit for the sprays around the drum is 1.0 gallon per thousand cubic feet of saturated gas exiting the CHEAF unit. This is between 7 and 10 times less than required for a Venturi type scrubber.

In addition, the CHEAF unit can be operated with a highly viscous scrubbing liquid, since atomization of the water is not critical to operation of the unit. The spray nozzles, which feed scrubbing liquid over the CHEAF drum, are operated at low pressures, typically 20 psig.

Once the contaminated gas has passed through the foam filter medium and has been contacted with the scrubbing liquid, the gas and the liquid droplets exit through one end of the drum into the entrainment separation section. A conventional, chevron-type mist eliminator is used to remove the bulk of the liquid droplets. A mesh type mist eliminator is then used to remove the extremely small liquid droplets and any residual moisture which is not collected by the chevron mist eliminator. The gas is then exhausted by an induced draft fan and discharged to the atmosphere. Spent scrubbing liquid is discharged by gravity from the entrainment separation section into a recirculation tank. This liquid can be recirculated back to the CHEAF filtration drum and used for scrubbing the incoming gas. A small bleed stream is taken to product recovery or to disposal. A cutaway drawing of the CHEAF system is shown in Figure 25.

The CHEAF system depends on three collection mechanisms for its operation:

1. Filtration
2. Impaction
3. Brownian motion (diffusion)

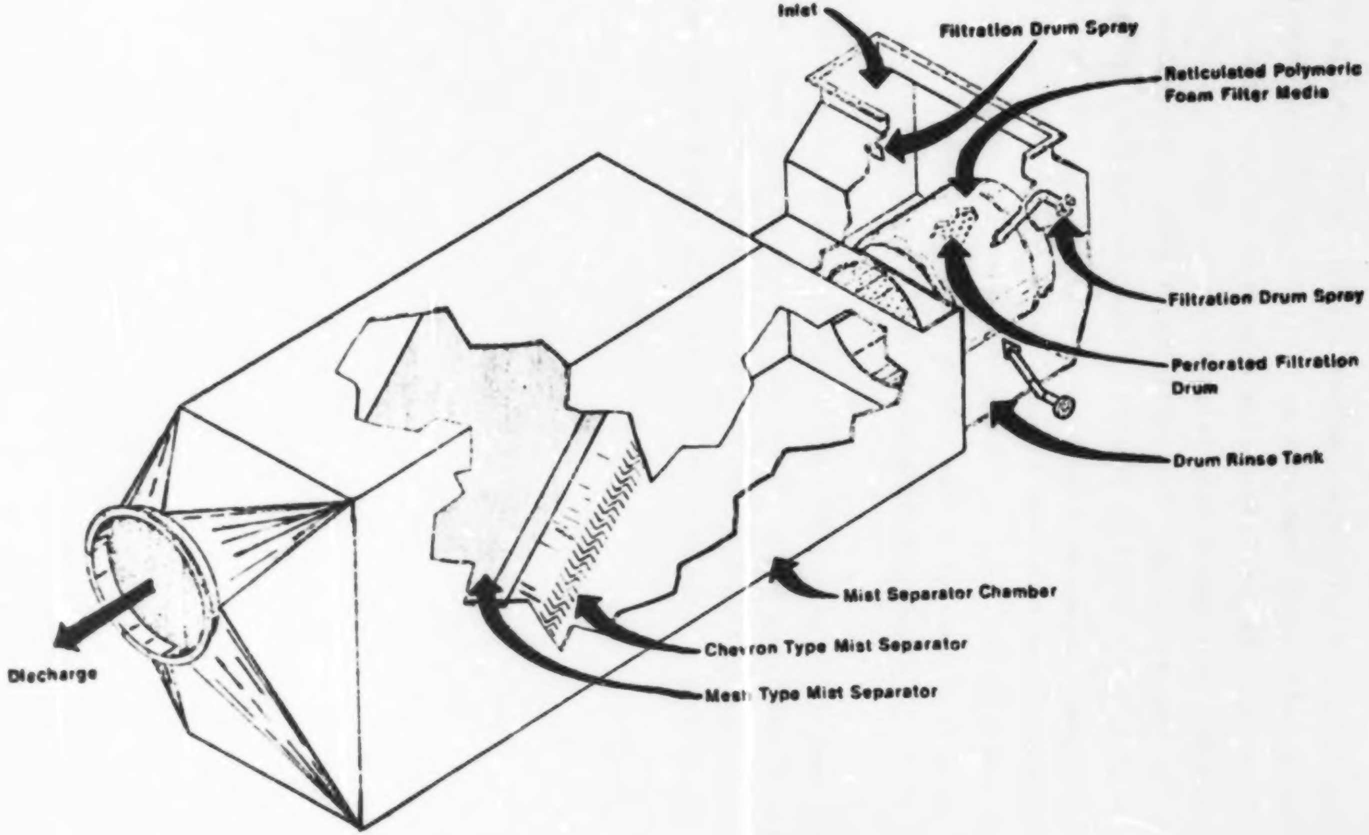
Inlet
Filtration Drum Spray
Reticulated Polymeric Foam Filter Media
Filtration Drum Spray
Perforated Filtration Drum
Drum Rinse Tank
Mist Separator Chamber
Chevron Type Mist Separator
Mesh Type Mist Separator
Discharge

Figure 25 . CHEAF unit, cutaway drawing

For large insoluble particulate matter and for undissolved large soluble particulate matter, the foam acts as a filter, physically impeding the flow of the particles and separating them from the gas stream. Filtration, however, contributes only slightly to the CHEAF system's high efficiency for fine particles. For particles of about 3 microns in diameter down to about 0.3 microns in diameter, impaction is the dominant collection mechanism. Impaction results when a projectile (the dust particle or aerosol droplet) runs into (impacts on) a collection object (the wetted fibers in the foam) and loses enough of its energy to separate from the bulk of the gas stream. Filtration and Brownian motion add slightly to the collection efficiency resulting from impaction.

Direct comparisons with other wet scrubbers indicate the CHEAF unit is capable of achieving higher collection efficiencies at lower energy input levels than conventional scrubbers. This is probably due to the filtration and diffusion effects being additive with impaction collection.

APPENDIX B

DATA REDUCTION FOR ANDERSEN IMPACTORS

Data reduction for the Andersen Impactors was done as follows. Once the weight gain on each impactor stage had been determined, a Hewlett Packard Model 9810 A calculator was used to calculate the following parameters:

- Total mass collected (grams)
- Total volume of gas sampled (ft^3 at NTP)
- Moisture content of gas stream (percent)
- Particulate mass concentration (grains/dscf)
- Flow rate through impactor (acfm)
- 50 percent effective cutoff diameter for each stage for unit density spherical particles (μm)
- Mass percent on each stage (percent)
- Cumulative mass percent ≤ each stage cutoff diameter (percent)
- Geometric mean diameter for each stage interval (μm)
- dM/d log D for each stage interval (grains/dscf).

The following data are entered into the calculator to obtain the above parameters:

- Barometric pressure (inches of mercury)
- Molecular weight of gas stream at meter (lb/lb-mole)
- Average static pressure at meter (inches of mercury)

- Average temperature at meter (^oF)
- Water collected in condenser and silica gel (grams)
- Gas volume at meter (ft^3)
- Average static pressure in duct (inches of water)
- Average duct temperature (^oF)
- Sampling duration (minutes)
- Temperature correction factor for Andersen impactor (see Figure 26)
- Particulate mass collected in probe and expander section prior to top stage (grams)
- Particulate mass collected on each impactor stage (grams)
- Particulate mass on back-up filter (grams).

The following calculations are performed by the calculator:

1. Total mass collected

$$M_T = M_p + \sum_{i = t}^{b} M_i + M_f$$

where M_T = total mass collected (grams)

M_p = mass collected in probe and impactor prior to top impactor stage (grams)

M_i = mass collected on impactor stage (grams)

$i = t$ = corresponds to the top impactor stage

$i = b$ = corresponds to the bottom impactor stage

M_f = mass collected on back-up filter (grams).

2. Volume H_2O vapor @ NTP

$$V_{H_2O} = (0.0473)\ (W)$$

where V_{H_2O} = volume of water vapor @ NTP (ft^3)

W = water collected (grams)

NTP = 29.92 in. Hg and $70^\circ F$.

3. Meter volume @ NTP

$$V_{ms} = V_m \left(\frac{P_b - P_m}{T_m + 460}\right)\left(\frac{530}{29.92}\right)$$

where V_{ms} = meter volume @ NTP (ft^3)

V_m = meter volume (ft^3)

P_b = barometric pressure ("Hg)

P_m = average static pressure at meter ("Hg)

T_m = average meter temperature ($^\circ F$).

4. Total volume sampled @ NTP, V_T (ft^3)

a. Outlet impactor only

$$V_T = V_{H_2O} + V_{ms}$$

b. Inlet impactor only

$$V_T = V_{ms}/F$$

where F = dry gas fraction.

5. Percent moisture, H_2O (%)

$$H_2O = (V_{H_2O}/V_T)\ (100)$$

6. Mass concentration, C_m (grains/dscf)

$$C_m = (M_T/V_{ms})\ (15.43 \text{ grains/gram})$$

7. Volume sampled at duct conditions

$$V_s = V_T \left(\frac{T_s + 460}{P_b - P_s/13.596}\right)\left(\frac{29.92}{530}\right)$$

where V_s = volume sampled at duct conditions (ft^3)

T_s = average duct temperature (^oF)

P_s = average duct static pressure ("H_2O).

8. Impactor flow rate

$$Q_I = V_s/t$$

where Q_I = impactor flow rate (acfm)

t = time (minutes).

9. Impactor stage size cutoffs

$$D_s = (tc)\ (k)\ (Q_I)^y$$

where D_s = impactor stage size cutoff (μm)

tc = temperature correction factor from Figure 26.

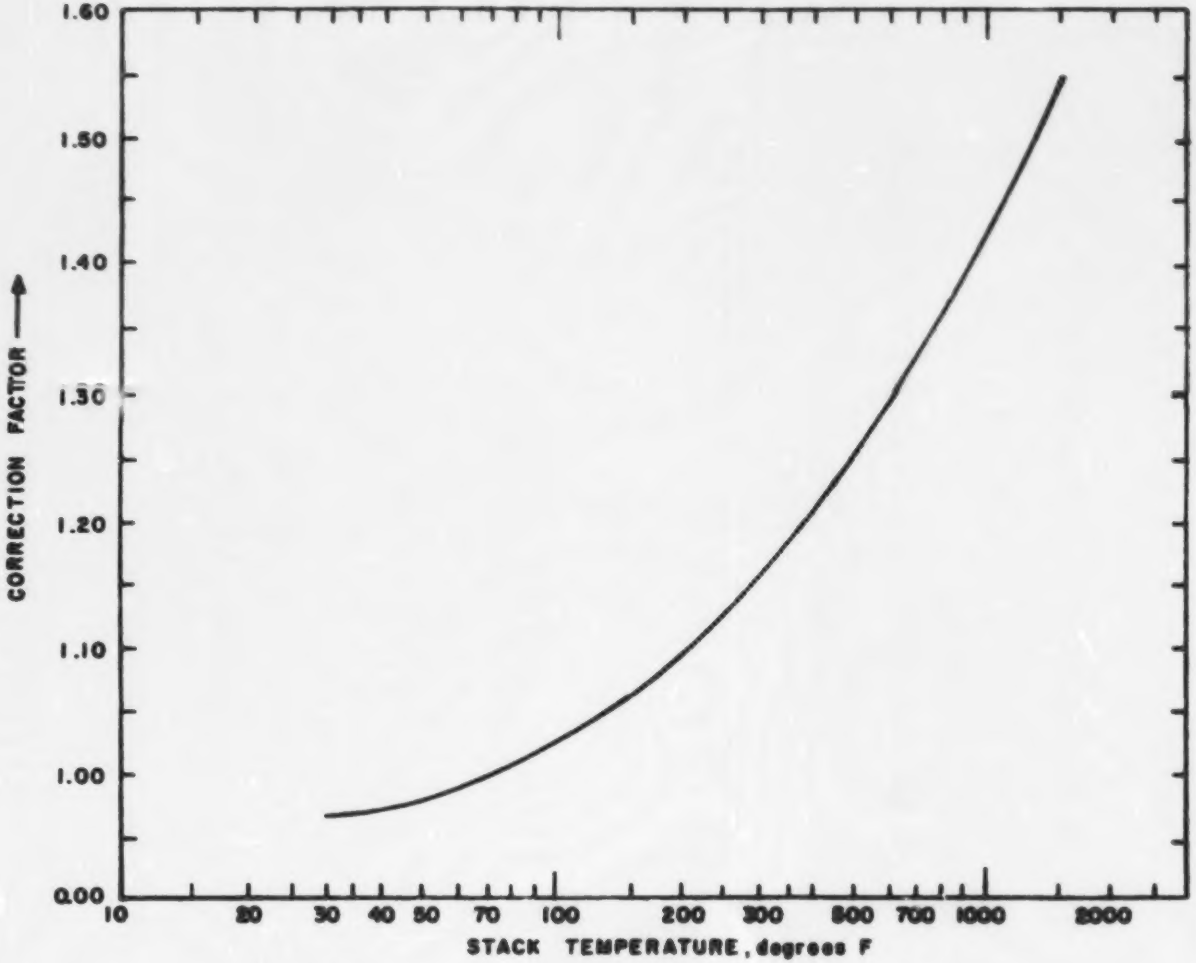

Figure 26. Temperature correction factor for aerodynamic size of particles captured in Andersen stack sampler

k = constant for each particular stage curve from Figure 27 for the Andersen Impactor.

y = exponent for each particular stage curve from Figure 27 for the Andersen Impactor.

10. Percent mass collected on back-up filter, P_F (%)

$$P_F = (M_f/M_T)\ 100$$

11. Percent mass collected on each impactor stage, P (%)

$$P_i = (M_i/M_T)\ 100$$

12. Percent mass collected in probe and impactor prior to top impactor stage, P_p (%)

$$P_p = (M_p/M_T)\ 100$$

13. Cumulative percent mass ≤ stage cutoff diameter for each impactor stage, C_{pn} (%)

$$C_{pn} = \sum_{i = b}^{n - 1} P_i + P_F$$

where L = b = corresponds to the bottom impactor stage

L = n = corresponds to the impactor stage of interest.

14. dM/d log D (grains/dscf)

$$dM/d \log D = \frac{(P_i/100)\ C_m}{(\log D_{i+1}) - (\log D_i)}$$

where P_i = percent mass collected on a particular stage(s) (%).

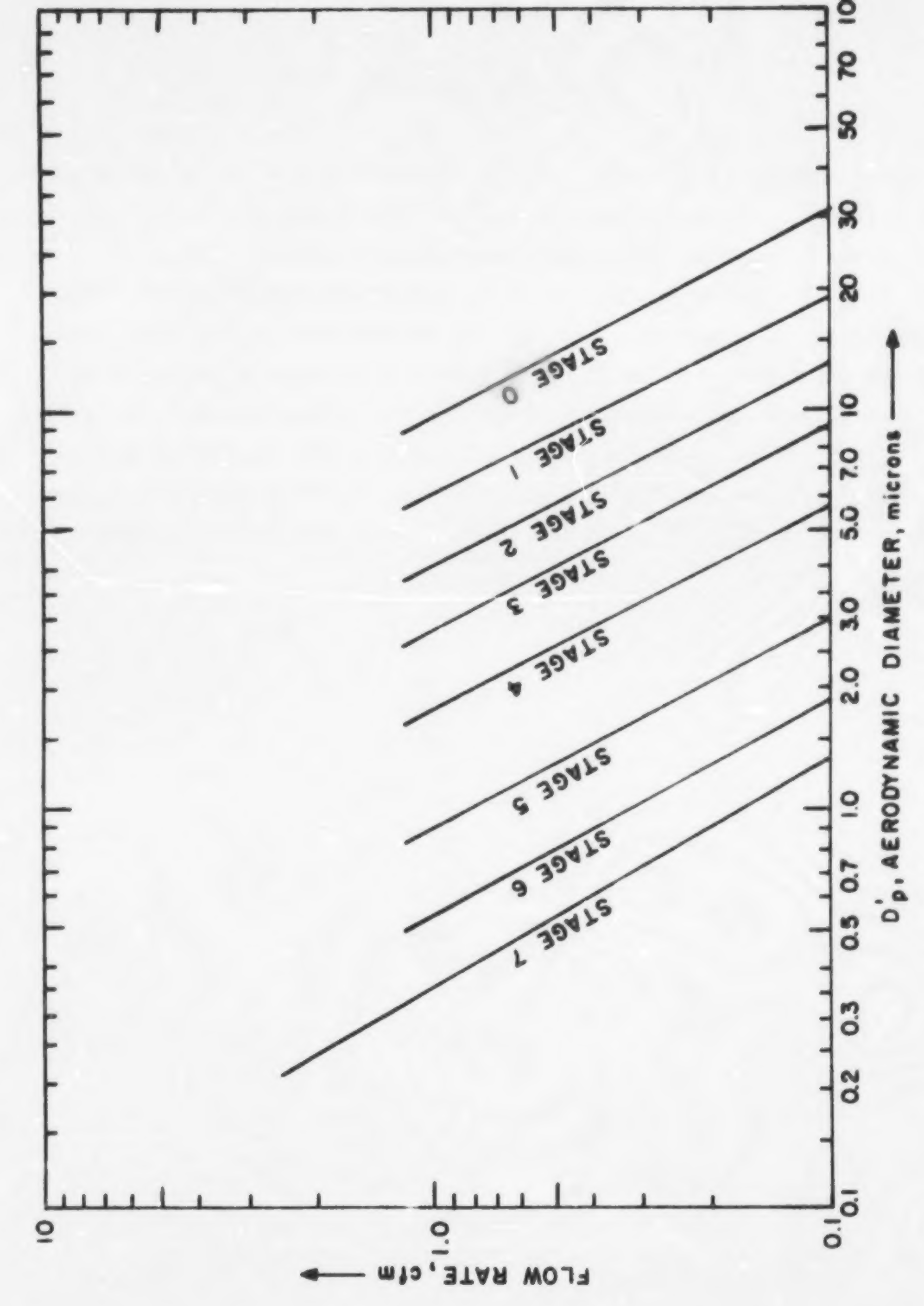

Figure 27. Aerodynamic diameter veruss flow rate through Andersen stack sampler

15. Geometric mean diameter, D_M (μm)

$$D_M = \sqrt{D_{i+1} \times D_i}$$

To get fractional efficiency, we plot the dM/d log D versus the geometric mean diameter for each stage interval for the inlet and outlet impactors. The curves from these plots yield the concentration for any given size particle. The ratio of the outlet concentration divided by the inlet concentration for any size particle is the penetration for that size. Because the CHEAF unit exhibited significant leakage between our inlet and outlet sampling points, we corrected the calculated dM/d log D for the effect of leakage before plotting curves. The correction was made by multiplying the outlet dM/d log D by the ratio of the total outlet flow of gas divided by the total inlet flow of gas, in dry standard cubic feet per minute.

APPENDIX C

ANDERSEN IMPACTOR DATA

ANDERSEN IMPACTOR

Date 11/5/75 Run # 2 (no dust feed)

Sample volume at STP (ft^3) = 8.4388

Moisture (%) = 1.6876

Concentration (grains/ft^3) = 0.0006

Impactor flow rate (acfm) = 0.6886

Location Outlet

Orifice D

Bar. press. ("Hg) = 29.94
Mw = 29.0
Avg. Pm (-"Hg) = 1.2
Avg. Tm (°F) = 80.0
H_2O (grams or %) = 28.7
Meter volume (ft^3) = 83.90
Avg. Ps ($\pm H_2O$) = 1.0
Avg. Ts (°F) = 84.0
Time (minutes) = 120
Correction factor = 1

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% ≤ stated size	dm/d log D	Geo. Mean (μm)
Probe & expander	0.0000	0.00		100.00		
0	0.0003	10.00	11.56	90.00	0.0006	9.14
1	0.0006	20.00	7.23	70.00	0.0004	5.91
2	0.0004	13.33	4.83	56.66	0.0006	4.03
3	0.005	16.66	3.35	40.00	0.0001	2.65
4	0.0001	3.33	2.10	36.66	0.0003	1.51
5	0.0004	13.33	1.08	23.33	0.0001	0.84
6	0.0001	3.33	0.66	20.00	0.0007	0.54
7	0.0006	20.00	0.44	0.00	0.0000	0.06
F	0.0000	0.00				
Total	0.0030					

ANDERSEN IMPACTOR

Date 11/11/75 Run # (3222-1)
Sample volume at STP (ft^3) = 12.4140
Moisture (%) = 0.8382
Concentration (grains/ft^3) = 0.0806
Impactor flow rate (acfm) = 0.6247

Location Inlet
Orifice E
Bar. press. ("Hg) = 30.00
Mw = 29
Avg. Pm (-"Hg) = 1.47
Avg. Tm (°F) = 74
H_2O (grams or %) = 2.2
Meter volume (ft^3) = 13.01
Avg. Ps ($\pm H_2O$) = 1
Avg. Ts (°F) = 74
Time (minutes) = 20
Correction factor = 1

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% ≤ stated size	dm/d log D	Geo. Mean (μm)
Probe & expander	0.0034	5.28		94.71		
0	0.0011	1.71	12.14	93.00	0.0025	9.60
1	0.0004	0.62	7.59	92.37	0.0072	6.21
2	0.0010	1.55	5.08	90.82	0.0055	4.23
3	0.0007	1.08	3.52	89.73	0.0214	2.78
4	0.0035	5.44	2.20	84.29	0.0846	1.58
5	0.0192	29.86	1.14	54.43	0.1276	0.89
6	0.0220	34.21	0.69	20.21	0.0812	0.57
7	0.0109	16.95	0.47	3.26	0.0016	0.06
F	0.0021	3.26				
Total						

ANDERSEN IMPACTOR

Date 11/11/75 Run # (3222-1)

Sample volume at STP (ft^3) = 80.8596

Moisture (%) = 1.5794

Concentration (grains/ft^3) = 0.0053

Impactor flow rate (acfm) = 0.6781

Location Outlet

Orifice D

Bar. press. ("Hg) = 30.00
Mw = 28.7
Avg. Pm (-"Hg) = 2.42
Avg. Tm (oF) = 79
H_2O (grams or %) = 27
Meter volume (ft^3) = 87.82
Avg. Ps ($\pm H_2O$) = 1
Avg. Ts (oF) = 74
Time (minutes) = 120
Correction factor = 1

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% ≤ stated size	dm/d log D	Geo. Mean (μm)
Probe & expander	0.0022	8.02		91.97		
0	0.0000	0.00	11.65	91.97	0.0002	9.21
1	0.0002	0.72	7.28	91.24	0.0001	5.96
2	0.0001	0.36	4.87	90.87	0.0004	4.06
3	0.0003	1.09	3.38	89.73	0.0002	2.67
4	0.0002	0.72	2.11	89.05	0.0021	1.52
5	0.0031	11.31	1.09	77.73	0.0044	0.85
6	0.0049	17.88	0.66	59.85	0.0089	0.54
7	0.0078	28.47	0.45	31.38	0.0010	0.06
F	0.0086	31.38				
Total	0.0274					

ANDERSEN IMPACTOR

Date 11/12/75 Run # (3222-2)

Sample volume at STP (ft^3) = 10.776

Moisture (%) = 0.895

Concentration (grains/ft^3) = 0.10258

Impactor flow rate (acfm) = 0.54225

Location Inlet

Orifice E

Bar. press. ("Hg) = 30.00
Mw = 29.00
Avg. Pm (-"Hg) = 1.5
Avg. Tm (°F) = 75
H_2O (grams or %) = 2.04
Meter volume (ft^3) = 11.32
Avg. Ps ($\pm H_2O$) = 1
Avg. Ts (°F) = 74
Time (minutes) = 20
Correction factor = 1

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% ≤ stated size	dm/d log D	Geo. Mean (μm)
Probe & expander	0.0021	2.95		97.04		
0	0.0008	1.12	13.03	95.92	0.00566	10.30
1	0.0008	1.12	8.14	94.79	0.01333	6.67
2	0.0016	2.25	5.46	92.54	0.01183	4.55
3	0.0013	1.83	3.79	90.70	0.02879	2.99
4	0.0041	5.77	2.36	84.93	0.109682	1.70
5	0.0215	30.28	1.22	54.65	0.15566	0.96
6	0.0231	32.53	0.75	22.11	0.11315	0.62
7	0.0130	18.30	0.51	3.80	0.00228	0.07
F	0.0027	3.80				
Total	0.0710					

ANDERSEN IMPACTOR

Date 11/12/75 Run # (3222-2)

Sample volume at STP (ft^3) = 78.7093

Moisture (%) = 1.4423

Concentration (grains/ft^3) = 0.0052

Impactor flow rate (acfm) = 0.6601

Location Outlet

Orifice D

Bar. press. ("Hg) = 30.00
Mw = 28.7
Avg. Pm (-"Hg) = 2.45
Avg. Tm (°F) = 76
H_2O (grams or %) = 24
Meter volume (ft^3) = 85.22
Avg. Ps (±H_2O) = 1
Avg. Ts (°F) = 74
Time (minutes) = 120
Correction factor = 1

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% ≤ stated size	dm/d log D	Geo. Mean (μm)
Probe & expander	0.0028	10.76		89.23		
0	0.0008	3.07	11.81	86.15	0.0007	9.34
1	0.0007	2.69	7.38	83.46	0.0006	6.04
2	0.0005	1.92	4.94	81.53	0.0011	4.11
3	0.0009	3.46	3.43	78.07	0.0008	2.71
4	0.0008	3.07	2.14	75.00	0.0017	1.54
5	0.0025	9.61	1.11	65.38	0.0027	0.86
6	0.0029	11.15	0.67	54.23	0.0067	0.55
7	0.0057	21.92	0.45	32.30	0.0010	0.06
F	0.0084	32.30				
Total	0.0260					

ANDERSEN IMPACTOR

Date 11/12/75 Run # (3222-3)

Sample volume at STP (ft^3) = 10.9630

Moisture (%) = 0.9492

Concentration (grains/ft^3) = 0.1040

Impactor flow rate (acfm) = 0.5529

Location Inlet

Orifice E

Bar. press. ("Hg) = 29.93
Mw = 29
Avg. Pm (-"Hg) = 1.5
Avg. Tm (°F) = 76
H_2O (grams or %) = 2.2
Meter volume (ft^3) = 11.56
Avg. Ps (±H_2O) = -1
Avg. Ts (°F) = 74
Time (minutes) = 20
Correction factor = 1

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% ≤ stated size	dm/d log D	Geo. Mean (μm)
Probe & expander	0.0032	4.37		95.62		
0	0.0012	1.63	12.9101	93.98	0.0070	10.20
1	0.0010	1.36	8.0688	92.62	0.0098	6.60
2	0.0012	1.63	5.4112	90.98	0.0125	4.50
3	0.0014	1.91	3.7541	89.07	0.0366	2.96
4	0.0053	7.24	2.3381	81.83	0.1016	1.68
5	0.0203	27.73	1.2175	54.09	0.1503	0.95
6	0.0227	31.01	0.7427	23.08	0.1170	0.61
7	0.0137	18.71	0.5064	4.37	0.0027	0.07
F	0.0032	4.37				
Total	0.0732					

ANDERSEN IMPACTOR

Date 11/12/75 Run # (3222-3)

Location Outlet

Sample volume at STP (ft^3) = 80.3666

Orifice D

Moisture (%) = 1.3537

Concentration ($grains/ft^3$) = 0.0051

Impactor flow rate (acfm) = 0.6756

Bar. press. ("Hg) = 29.93
Mw = 28.7
Avg. Pm (-"Hg) = 2.50
Avg. Tm (°F) = 78
H_2O (grams or %) = 23
Meter volume (ft^3) = 87.80
Avg. Ps ($\underline{+}H_2O$) = 1
Avg. Ts (°F) = 74
Time (minutes) = 120
Correction factor = 1

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% ≤ stated size	dm/d log D	Geo. Mean (μm)
Probe & expander	0.0022	8.42		91.51		
0	0.0007	2.68	11.67	88.88	0.0008	9.23
1	0.0008	3.06	7.29	85.82	0.0007	5.97
2	0.0006	2.29	4.88	83.52	0.0010	4.07
3	0.0008	3.06	3.39	80.45	0.0006	2.68
4	0.0006	2.29	2.12	78.16	0.0016	1.52
5	0.0024	9.19	1.09	68.96	0.0036	0.85
6	0.0040	15.32	0.66	53.63	0.0070	0.54
7	0.0061	23.37	0.45	30.26	0.0009	0.06
F	0.0079	30.26				
Total	0.0261					

ANDERSEN IMPACTOR

Date 11/13/75 Run # (3222-4)
Sample volume at STP (ft^3) = 10.2335
Moisture (%) = 1.0169
Concentration ($grains/ft^3$) = 0.1190
Impactor flow rate (acfm) = 0.5260

Location Inlet
Orifice E
Bar. press. ("Hg) = 29.37
Mw = 29
Avg. Pm (-"Hg) = 1.5
Avg. Tm (°F) = 76
H_2O (grams or %) = 2.2
Meter volume (ft^3) = 11.00
Avg. Ps ($\pm H_2O$) = -1
Avg. Ts (°F) = 74
Time (minutes) = 20
Correction factor = 1

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% ≤ stated size	dm/d log D	Geo. Mean (μm)
Probe & expander	0.0016	2.04		97.95		
0	0.0023	2.94	13.2365	95.00	0.0060	10.46
1	0.0008	1.02	8.2728	93.98	0.0053	6.77
2	0.0006	0.76	5.5507	93.21	0.0134	4.62
3	0.0014	1.79	3.8503	91.42	0.0126	3.03
4	0.0017	2.17	2.3959	89.24	0.1088	1.72
5	0.0202	25.86	1.2489	63.38	0.1637	0.97
6	0.0230	29.44	0.7630	33.93	0.2136	0.63
7	0.0232	29.70	0.5212	4.22	0.0029	0.07
F	0.0033	4.22				
Total	0.0781					

ANDERSEN IMPACTOR

Date 11/13/75   Run # (3222-4)

Sample volume at STP (ft^3) = 73.3436

Moisture (%) = 1.1286

Concentration ($grains/ft^3$) = 0.0052

Impactor flow rate (acfm) = 0.6319

Location Outlet

Orifice D

Bar. press. ("Hg) = 29.37
Mw = 28.7
Avg. Pm (-"Hg) = 2.4
Avg. Tm (°F) = 78
H_2O (grams or %) = 17.5
Meter volume (ft^3) = 81.68
Avg. Ps ($\underline{+}H_2O$) = 1
Avg. Ts (°F) = 77
Time (minutes) = 120
Correction factor = 1

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% ≤ stated size	dm/d log D	Geo. Mean (μm)
Probe & expander	0.0018	7.40		92.59		
0	0.0000	0.00	12.0771	92.59	0.0002	9.54
1	0.0002	0.82	7.5482	91.76	0.0004	6.17
2	0.0003	1.23	5.0553	90.42	0.0007	4.21
3	0.0005	0.05	3.5086	88.47	0.0011	2.77
4	0.0011	4.52	2.1905	83.95	0.0026	1.57
5	0.0025	14.40	1.1374	69.54	0.0052	0.88
6	0.0053	21.81	0.6913	47.73	0.0051	0.56
7	0.0040	16.46	0.4690	31.27	0.0010	0.06
F	0.0076	31.27				
Total	0.0243					

ANDERSEN IMPACTOR

Date 11/24/75 Run # 2222
Sample volume at STP (ft^3) = 7.4563
Moisture (%) = 1.0150
Concentration ($grains/ft^3$) = 0.0721
Impactor flow rate (acfm) = 0.4934

Location Inlet
Orifice E
Bar. press. ("Hg) = 30.20
Mw = 29
Avg. Pm (-"Hg) = 1.8
Avg. Tm (^oF) = 69.5
H_2O (grams or %) = 1.6
Meter volume (ft^3) = 7.77
Avg. Ps ($\pm H_2O$) = -0.37
Avg. Ts (^oF) = 71
Time (minutes) = 15
Correction factor = 1

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% $\leq$ stated size	dm/d log D	Geo. Mean (μm)
Probe & expander	0.0028	8.11		91.88		
0	0.0003	0.86	13.6671	91.01	0.0041	10.80
1	0.0004	1.15	8.5419	89.85	0.0048	6.99
2	0.0004	1.15	5.7350	88.69	0.0118	4.77
3	0.0009	2.60	3.9774	86.08	0.0294	3.13
4	0.0029	8.40	2.4721	77.68	0.0881	1.78
5	0.0119	34.49	1.2904	43.10	0.0500	1.00
6	0.0051	14.78	0.7897	28.40	0.1004	0.65
7	0.0079	22.89	0.5408	5.50	0.0023	0.07
F	0.0019	5.50				
Total	0.0345					

ANDERSEN IMPACTOR

Date 11/24/75 Run # 2222

Sample volume at STP (ft^3) = 79.7884

Moisture (%) = 1.3635

Concentration ($grains/ft^3$) = 0.0046

Impactor flow rate (acfm) = 0.6661

Location Outlet

Orifice D

Bar. press. ("Hg) = 30.20
Mw = 28.7
Avg. Pm (-"Hg) = 2.62
Avg. Tm (°F) = 73
H_2O (grams or %) = 23
Meter volume (ft^3) = 85.88
Avg. Ps ($\pm H_2O$) = 0.34
Avg. Ts (°F) = 76
Time (minutes) = 120
Correction factor = 1

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% ≤ stated size	dm/d log D	Geo. Mean (μm)
Probe & expander	0.0009	3.8462		96.1538		
0	0.0002	2.8547	11.7623	95.2991	0.0004	9.2989
1	0.0004	1.7094	7.3515	93.5897	0.0006	6.0146
2	0.0005	2.1368	4.9209	91.4530	0.0009	4.0999
3	0.0007	2.9915	3.4159	88.4615	0.0012	2.7003
4	0.0012	5.1282	2.1346	83.3333	0.0023	1.5374
5	0.0034	14.5200	1.1072	68.8034	0.0051	0.8625
6	0.0056	23.9316	0.6719	44.8718	0.0047	0.5529
7	0.0041	17.5214	0.4549	27.3504	0.0008	0.0674
F	0.0064	27.3504				
Total	0.0234					

ANDERSEN IMPACTOR

Date 12/3/75 Run # 1222-1A
Sample volume at STP (ft^3) = 7.5612
Moisture (%) = 1.0001
Concentration (grains/ft^3) = 0.0946
Impactor flow rate (acfm) = 0.5074

Location Inlet
Orifice E
Bar. press. ("Hg) = 29.97
Mw = 29
Avg. Pm (-"Hg) = 1.3
Avg. Tm (°F) = 74.5
H_2O (grams or %) = 1.6
Meter volume (ft^3) = 7.88
Avg. Ps ($\pm H_2O$) = -0.04
Avg. Ts (°F) = 75
Time (minutes) = 15
Correction factor = 1

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% ≤ stated size	dm/d log D	Geo. Mean (μm)
Probe & expander	0.0016	3.4858		96.5142		
0	0.0000	0.0000	13.4762	96.5142	0.0000	10.6539
1	0.0000	0.0000	8.4226	96.5142	0.0000	6.9004
2	0.0000	0.0000	5.6533	96.5142	0.0233	4.7082
3	0.0018	3.9216	3.9210	92.5926	0.0029	3.0921
4	0.0003	0.6536	2.4383	91.9389	0.0737	1.7611
5	0.0101	22.0043	1.2719	69.9346	0.0714	0.9947
6	0.0004	16.1220	0.7778	53.8126	0.1087	0.6433
7	0.0083	18.9542	0.5321	34.8584	0.0191	0.0729
F	0.0160	34.8584				
Total	0.0459					

ANDERSEN IMPACTOR

Date 12/3/75 Run # 1222-1A
Sample volume at STP (ft^3) = 73.0685
Moisture (%) = 1.0357
Concentration (grains/ft^3) = 0.0093
Impactor flow rate (acfm) = 0.6239

Location Outlet
Orifice D
Bar. press. ("Hg) = 29.97
Mw = 28.7
Avg. Pm (-"Hg) = 2.1
Avg. Tm (°F) = 76.5
H_2O (grams or %) = 16
Meter volume (ft^3) = 78.60
Avg. Ps (±H_2O) = 0.34
Avg. Ts (°F) = 84
Time (minutes) = 120
Correction factor = 1

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% ≤ stated size	dm/d log D	Geo. Mean (μm)
Probe & expander	0.0012	2.7586		97.2414		
0	0.0000	0.0000	12.1540	97.2414	0.0005	9.6086
1	0.0005	1.1494	7.5963	96.0920	0.0010	6.2170
2	0.0008	1.8391	5.0881	94.2529	0.0015	4.2388
3	0.0011	2.5287	3.5312	91.7241	0.0021	2.7898
4	0.0020	4.5977	2.2041	87.1264	0.0077	1.5885
5	0.0102	23.4483	1.1448	63.6782	0.0161	0.8927
6	0.0163	37.4713	0.6960	26.2069	0.0117	0.5734
7	0.0092	21.1494	0.4724	5.0575	0.0003	0.0687
F	0.0022	5.0575				
Total	0.0435					

ANDERSEN IMPACTOR

Date 11/14/75 Run # (3212-1)
Sample volume at STP (ft^3) = 7.4943
Moisture (%) = 0.9467
Concentration ($grains/ft^3$) = 0.1328
Impactor flow rate (acfm) = 0.5136

Location Inlet
Orifice E
Bar. press. ("Hg) = 29.37
Mw = 29
Avg. Pm (-"Hg) = 1.72
Avg. Tm (°F) = 73
H_2O (grams or %) = 1.5
Meter volume (ft^3) = 8.08
Avg. Ps ($\pm H_2O$) = -1
Avg. Ts (°F) = 74
Time (minutes) = 15
Correction factor = 1

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% ≤ stated size	dm/d log D	Geo. Mean (μm)
Probe & expander	0.0033	5.1643		94.8357		
0	0.0007	1.0955	13.3952	93.7402	0.0071	10.5898
1	0.0007	1.0955	8.3720	92.6448	0.0072	6.8585
2	0.0006	0.9390	5.6187	91.7058	0.0183	4.6794
3	0.0014	2.1909	3.8972	89.5149	0.0383	3.0736
4	0.0038	5.9468	2.4240	83.5681	0.1267	1.7505
5	0.0175	27.3865	1.2642	56.1815	0.1925	0.9884
6	0.0198	30.9859	0.7728	25.1956	0.1460	0.6390
7	0.0116	18.1534	0.5284	7.0423	0.0054	0.0727
F	0.0045	7.0423				
Total	0.0639					

ANDERSEN IMPACTOR

Date 11/14/75 Run # (3212-1)
Sample volume at STP (ft^3) = 80.2594
Moisture (%) = 1.3614
Concentration (grains/ft^3) = 0.0046
Impactor flow rate (acfm) = 0.6966

Location Outlet
Orifice D
Bar. press. ("Hg) = 29.37
Mw = 28.7
Avg. Pm (-"Hg) = 2.33
Avg. Tm (°F) = 76
H_2O (grams or %) = 23.1
Meter volume (ft^3) = 88.61
Avg. Ps ($\pm H_2O$) = 1
Avg. Ts (°F) = 81
Time (minutes) = 120
Correction factor = 1

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% ≤ stated size	dm/d log D	Geo. Mean (μm)
Probe & expander	0.0009	3.7815		96.2185		
0	0.0004	1.6807	11.5023	94.5378	0.0005	9.0933
1	0.0005	2.1008	7.1889	92.4370	0.0007	5.8803
2	0.0006	2.5210	4.8100	89.9160	0.0010	4.0077
3	0.0008	3.3613	3.3393	86.5546	0.0011	2.6408
4	0.0011	4.6218	2.0884	81.9328	0.0029	1.5034
5	0.0042	7.6471	1.0822	64.2857	0.0052	0.8426
6	0.0058	24.3697	0.6560	39.9160	0.0048	0.5393
7	0.0042	17.6471	0.4434	22.2689	0.0006	0.0666
F	0.0053	22.2689				
Total	0.0238					

ANDERSEN IMPACTOR

Date 11/15/75 Run # (3212-2)

Sample volume at STP (ft^3) = 7.1999

Moisture (%) = 0.8869

Concentration ($grains/ft^3$) = 0.1784

Impactor flow rate (acfm) = 0.4858

Location Inlet

Orifice E

Bar. press. ("Hg) = 29.82
Mw = 29
Avg. Pm (-"Hg) = 1.4
Avg. Tm (°F) = 72
H_2O (grams or %) = 1.35
Meter volume (ft^3) = 7.54
Avg. Ps ($\pm H_2O$) = -1
Avg. Ts (°F) = 74
Time (minutes) = 15
Correction factor = 1

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% ≤ stated size	dm/d log D	Geo. Mean (μm)
Probe & expander	0.0015	1.8182		98.1818		
0	0.0010	1.2121	13.7732	96.9697	0.0085	10.8887
1	0.0008	0.9697	8.6083	96.0000	0.0100	7.0540
2	0.0008	0.9697	5.7804	95.0303	0.1959	4.8137
3	0.0144	17.4545	4.0087	77.5758	0.0115	3.1599
4	0.0011	1.3333	2.4909	76.2424	0.0628	1.7999
5	0.0082	9.9394	1.3006	66.3030	0.1319	1.0177
6	0.0130	15.7576	0.7963	50.5455	0.1528	0.6591
7	0.0116	14.0606	0.5456	36.4848	0.0375	0.0739
F	0.0306	36.4848				
Total	0.0825					

ANDERSEN IMPACTOR

Date 11/15/75 Run # (3212-2)
Sample volume at STP (ft^3) = 71.5421
Moisture (%) = 1.0909
Concentration (grains/ft^3) = 0.0044
Impactor flow rate (acfm) = 0.6093

Location Outlet
Orifice D
Bar. press. ("Hg) = 29.82
Mw = 28.7
Avg. Pm (-"Hg) = 2.25
Avg. Tm (^{o}F) = 72
H_2O (grams or %) = 16.5
Meter volume (ft^3) = 77.10
Avg. Ps ($\pm H_2O$) = 1
Avg. Ts (^{o}F) = 79
Time (minutes) = 120
Correction factor = 1

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% $\leq$ stated size	dm/d log D	Geo. Mean (μm)
Probe & expander	0.0009	4.4335		95.5665		
0	0.0004	1.9704	12.2989	93.5961	0.0007	9.7231
1	0.0007	3.4483	7.6868	90.1478	0.0008	6.2918
2	0.0006	2.9557	5.1500	87.1921	0.0007	4.2902
3	0.0005	2.4631	3.5739	84.7291	0.0010	2.8230
4	0.0009	4.4335	2.2208	80.2956	0.0022	1.6074
5	0.0029	14.2857	1.1587	66.0099	0.0048	0.9038
6	0.0048	23.6453	0.7050	42.3645	0.0045	0.5810
7	0.0035	17.2414	0.4789	25.1232	0.0007	0.0692
F	0.0051	25.1232				
Total	0.0203					

ANDERSEN IMPACTOR

Date 11/22/75 Run # (3221-1)

Sample volume at STP (ft^3) = 6.5745

Moisture (%) = 1.2231

Concentration ($grains/ft^3$) = 0.1226

Impactor flow rate (acfm) = 0.4408

Location Inlet

Orifice E

Bar. press. ("Hg) = 29.87
Mw = 29
Avg. Pm (-"Hg) = 1.45
Avg. Tm (°F) = 74
H_2O (grams or %) = 1.7
Meter volume (ft^3) = 6.89
Avg. Ps ($\pm H_2O$) = -1
Avg. Ts (°F) = 74
Time (minutes) = 15
Correction factor = 1

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% ≤ stated size	dm/d log D	Geo. Mean (μm)
Probe & expander	0.0028	5.4263		94.5736		
0	0.0000	0.0000	14.4585	94.5736	0.0070	11.4305
1	0.0008	1.1628	9.0366	93.4108	0.0083	7.4086
2	0.0006	1.1628	6.0739	92.2481	0.0134	5.0574
3	0.0009	1.7442	4.2110	90.5039	0.0229	3.3165
4	0.0020	3.8759	2.6120	86.6279	0.0054	1.8894
5	0.0113	21.8992	1.3666	64.7287	0.2355	11.0708
6	0.0210	40.6977	0.8390	24.0310	0.1403	0.6958
7	0.0096	18.6046	0.5770	51.4263	0.0037	0.0760
F	0.0028	5.4263				
Total	0.0516					

ANDERSEN IMPACTOR

Date 11/22/75 Run # 3221-1

Sample volume at STP (ft^3) = 66.0387

Moisture (%) = 1.3394

Concentration (grains/ft^3) = 0.0035

Impactor flow rate (acfm) = 0.5667

Location Outlet

Orifice D

Bar. press. ("Hg) = 29.87
Mw = 28.7
Avg. Pm (-"Hg) = 1.8
Avg. Tm (°F) = 76
H_2O (grams or %) = 18.7
Meter volume (ft^3) = 70.25
Avg. Ps ($\pm H_2O$) = 1
Avg. Ts (°F) = 84
Time (minutes) = 120
Correction factor = 1

Stage	Net weight (gm)	% on stage	Size cutoff (µm)	% ≤ stated size	dm/d log D	Geo. Mean (µm)
Probe & expander	0.0003	2.0403		97.9592		
0	0.0002	1.3605	12.7528	96.5986	0.0002	10.0820
1	0.0002	1.3605	7.9705	95.2381	0.0003	6.5264
2	0.0002	1.3605	5.3439	93.8776	0.0007	4.4513
3	0.0005	3.4014	3.7077	90.4762	0.0007	2.9267
4	0.0006	4.0816	2.3103	86.3946	0.0014	1.6667
5	0.0017	11.5646	1.2024	74.8299	0.0040	0.9388
6	0.0086	24.4896	0.7330	50.3401	0.0048	0.6050
7	0.0034	23.1293	0.4993	27.2109	0.0006	0.0707
F	0.0040	27.2109				
Total	0.0147					

ANDERSEN IMPACTOR

Date 11/22/75 Run # 3221-2

Sample volume at STP (ft^3) = 6.5584

Moisture (%) = 1.2261

Concentration (grains/ft^3) = 0.1248

Impactor flow rate (acfm) = 0.4419

Location Inlet

Orifice E

Bar. press. ("Hg) = 29.87
Mw = 29
Avg. Pm (-"Hg) = 1.45
Avg. Tm (^oF) = 73
H_2O (grams or %) = 1.7
Meter volume (ft^3) = 6.86
Avg. Ps ($\pm H_2O$) = -1
Avg. Ts (^oF) = 74
Time (minutes) = 15
Correction factor = 1

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% $\le$ stated size	dm/d log D	Geo. Mean (μm)
Probe & expander	0.0019	3.6260		96.3740		
0	0.0007	1.3359	14.4408	95.0382	0.0082	11.4164
1	0.0007	1.3359	9.0255	93.7023	0.0097	7.3994
2	0.0007	1.3359	6.0663	92.3664	0.0165	5.0511
3	0.0011	2.0992	4.2058	90.2672	0.0390	3.3125
4	0.0034	6.4885	2.6089	83.7786	0.1160	1.8870
5	0.0137	26.1450	1.3649	57.6336	0.1798	1.0694
6	0.0160	30.5344	0.8379	27.0992	0.1699	0.6948
7	0.0116	22.1374	0.5762	4.9618	0.0035	0.0759
F	0.0026	4.9618				
Total	0.0524					

ANDERSEN IMPACTOR

Date 11/22/75 Run # 3221-2
Sample volume at STP (ft^3) = 65.8084
Moisture (%) = 1.3297
Concentration (grains/ft^3) = 0.0038
Impactor flow rate (acfm) = 0.5647

Location Outlet
Orifice D
Bar. press. ("Hg) = 29.87
Mw = 28.7
Avg. Pm (-"Hg) = 1.9
Avg. Tm (°F) = 74
H_2O (grams or %) = 18.5
Meter volume (ft^3) = 70
Avg. Ps ($\pm H_2O$) = 1
Avg. Ts (°F) = 84
Time (minutes) =120
Correction factor = 1

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% ≤ stated size	dm/d log D	Geo. Mean (μm)
Probe & expander	0.0000	0.0000		100.0000		
0	0.0003	1.8987	12.7751	98.1013	0.0008	10.0996
1	0.0007	4.4304	7.9844	93.6709	0.0005	6.5379
2	0.0004	2.5316	5.3535	91.1392	0.0012	4.4592
3	0.0008	5.0633	3.7143	86.0759	0.0010	2.9318
4	0.0009	5.6962	2.3142	80.3797	0.0018	1.6696
5	0.0021	13.2911	1.2045	67.0886	0.0039	0.9405
6	0.0035	22.1519	0.7344	44.9367	0.0046	0.6062
7	0.0032	20.2532	0.5003	24.6835	0.0005	0.0707
F	0.0039	24.6835				
Total	0.0158					

ANDERSEN IMPACTOR

Date 11/21/75 Run # 3223-1
Sample volume at STP (ft^3) = 5.9974
Moisture (%) = 1.1491
Concentration (grains/ft^3) = 0.12068
Impactor flow rate (acfm) = 0.4736

Location Inlet
Orifice E
Bar. press. ("Hg) = 29.74
Mw = 29
Avg. Pm (-"Hg) = 1.45
Avg. Tm (°F) = 76
H_2O (grams or %) = 1.7
Meter volume (ft^3) = 7.4
Avg. Ps (±H_2O) = -1
Avg. Ts (°F) = 74
Time (minutes) = 15
Correction factor = 1

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% ≤ stated size	dm/d log D	Geo. Mean (μm)
Probe & expander	0.0033	6.010		93.900		
0	0.0014	2.589	13.9499	91.312	0.0087	11.0283
1	0.0008	1.479	8.7187	89.834	0.0142	7.1454
2	0.0011	2.033	5.8561	87.800	0.0210	4.8765
3	0.0015	2.772	4.0608	85.028	0.0216	3.2003
4	0.0020	3.697	2.5221	81.331	0.0878	1.8230
5	0.0111	20.518	1.3176	60.813	0.1803	1.0314
6	0.0172	31.793	0.8073	29.020	29.020	0.1621
7	0.0119	21.996	0.5537	7.024	0.0049	0.0744
F	0.0038	7.024				
Total	0.0541					

ANDERSEN IMPACTOR

Date 11/21/75 Run # 3223-1

Sample volume at STP (ft^3) = 70.9377

Moisture (%) = 1.8670

Concentration ($grains/ft^3$) = 0.0034

Impactor flow rate (acfm) = 0.6136

Location Outlet

Orifice D

Bar. press. ("Hg) = 29.74
Mw = 29
Avg. Pm (-"Hg) = 2.1
Avg. Tm (°F) = 78
H_2O (grams or %) = 28
Meter volume (ft^3) = 76.51
Avg. Ps (±H_2O) = 1
Avg. Ts (°F) = 86
Time (minutes) = 120
Correction factor = 1

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% ≤ stated size	dm/d log D	Geo. Mean (μm)
Probe & expander	0.0011	7.1895		92.8105		
0	0.0004	2.6144	12.2552	90.1961	0.0003	9.6886
1	0.0003	1.9608	7.6505	88.2353	0.0005	6.2692
2	0.0004	2.6144	5.1313	85.6209	0.0006	4.2747
3	0.0004	2.6144	3.5611	83.0065	0.0011	2.8130
4	0.0010	6.5359	2.2220	76.4706	0.0008	1.6017
5	0.0010	6.5359	1.1545	69.9346	0.0045	0.9004
6	0.0044	28.7582	0.7023	41.1765	0.0041	0.5787
7	0.0031	20.2614	0.4769	20.9150	0.0004	0.0691
F	0.0032	20.9150				
Total	0.0153					

ANDERSEN IMPACTOR

Date 11/23/75   Run # 3223-2

Sample volume at STP (ft^3) = 5.1961

Moisture (%) = 1.4565

Concentration ($grains/ft^3$) = 0.1211

Impactor flow rate (acfm) = 0.3439

Location Inlet

Orifice E

Bar. press. ("Hg) = 30.41
Mw = 29
Avg. Pm (-"Hg) = 1
Avg. Tm (°F) = 72
H_2O (grams or %) = 1.6
Meter volume (ft^3) = 5.23
Avg. Ps ($\pm H_2O$) = -1
Avg. Ts (°F) = 74
Time (minutes) = 15
Correction factor = 1

Stage	Net weight (gm)	% on stage	Size cutoff (µm)	% ≤ stated size	dm/d log D	Geo. Mean (µm)
Probe & expander	0.0015	3.7313		96.2687		
0	0.0007	1.7413	16.3701	94.5274	0.0074	12.9417
1	0.0005	1.2438	10.2313	93.2836	0.0035	8.3985
2	0.0002	0.4975	6.8941	92.7861	0.0095	5.7382
3	0.0005	1.2438	4.7761	91.5423	0.0216	3.7531
4	0.0015	3.7313	2.9493	87.8109	0.0723	2.1389
5	0.0067	16.6667	1.5512	71.1443	0.1904	1.2196
6	0.0132	32.8358	0.9589	38.3085	0.1825	0.7980
7	0.0096	23.8806	0.6658	14.4279	0.0096	0.0816
F	0.0058	14.4279				
Total	0.0402					

ANDERSEN IMPACTOR

Date 11/23/75 Run # 3223-2

Sample volume at STP (ft^3) = 56.9631

Moisture (%) = 1.3203

Concentration (grains/ft^3) = 0.0035

Impactor flow rate (acfm) = 0.4757

Location Outlet

Orifice D

Bar. press. ("Hg) = 30.41

Mw = 28.7

Avg. Pm (-"Hg) = 1.6

Avg. Tm (°F) = 72

H_2O (grams or %) = 15.9

Meter volume (ft^3) = 58.61

Avg. Ps ($\underline{+}H_2O$) = 1

Avg. Ts (°F) = 79

Time (minutes) =120

Correction factor = 1

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% ≤ stated size	dm/d log D	Geo. Mean (μm)
Probe & expander	0.0011	8.5271		91.4729		
0	0.0000	0.0000	13.9192	91.4729	0.0000	11.0041
1	0.0000	0.0000	8.6995	91.4729	0.0000	7.1295
2	0.0000	0.0000	5.8429	91.4729	0.0002	4.8656
3	0.0001	0.7752	4.0518	90.6977	0.0000	3.1933
4	0.0002	0.0000	2.5167	90.6977	0.0007	1.8190
5	0.0007	5.4264	1.3147	85.2713	0.0031	1.0290
6	0.0028	18.6047	0.5523	44.9612	0.0047	0.6669
7	0.0028	21.7054				
F	0.0058	44.9612				
Total	0.0129					

ANDERSEN IMPACTOR

Date 11/19/75 Run # 3122

Sample volume at STP (ft^3) = 8.9309

Moisture (%) = 0.9003

Concentration ($grains/ft^3$) = 0.0824

Impactor flow rate (acfm) = 0.5922

Location Inlet

Orifice E

Bar. press. ("Hg) = 30.31
Mw = 29
Avg. Pm (-"Hg) = 2.07
Avg. Tm (°F) = 75.7
H_2O (grams or %) = 1.7
Meter volume (ft^3) = 9.48
Avg. Ps ($\pm H_2O$) = - 0.42
Avg. Ts (°F) = 74
Time (minutes) = 15
Correction factor = 1

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% ≤ stated size	dm/d log D	Geo. Mean (μm)
Probe & expander	0.0051	10.7822		89.2177		
0	0.0018	3.8054	12.4746	85.4122	0.0051	9.8620
1	0.0006	1.2684	7.7966	84.1437	0.0080	6.3826
2	0.0008	1.6913	5.2250	82.4524	0.0098	4.3525
3	0.0009	1.9027	3.6257	80.5496	0.0161	2.8631
4	0.0019	4.0169	2.2609	76.5327	0.0429	1.6303
5	0.0070	14.7991	1.1756	61.7336	0.0873	0.9173
6	0.0108	22.8329	0.7158	38.9006	0.1457	0.5903
7	0.0140	29.5983	0.4868	9.3023	0.0045	0.0697
F	0.0044	9.3023				
Total	0.0473					

ANDERSEN IMPACTOR

Date 11/19/75 Run # 3122

Sample volume at STP (ft^3) = 75.8611

Moisture (%) = 1.4208

Concentration (grains/ft^3) = 0.0048

Impactor flow rate (acfm) = 0.6334

Location Outlet

Orifice D

Bar. press. ("Hg) = 30.32
Mw = 28.7
Avg. Pm (-"Hg) = 3.02
Avg. Tm (°F) = 77.8
H_2O (grams or %) = 22.5
Meter volume (ft^3) = 83.2
Avg. Ps ($\pm H_2O$) = 1.0
Avg. Ts (°F) = 80
Time (minutes) = 120
Correction factor = 1

Stage	Net weight (gm)	% on stage	Size cutoff (µm)	% ≤ stated size	dm/d log D	Geo. Mean (µm)
Probe & expander	0.0015	5.4377		93.5622		
0	0.0005	2.1459	12.0616	91.4163	0.0003	9.5355
1	0.0003	1.2875	7.5385	90.1287	0.0005	6.1692
2	0.0005	2.1459	5.0486	87.9828	0.000	4.2060
3	0.0006	2.5751	3.5040	85.4077	0.0010	2.7687
4	0.0010	4.2918	2.1877	81.1158	0.0026	1.5764
5	0.0037	15.8798	1.1359	65.2360	0.0056	0.8855
6	0.0059	25.3218	0.6903	39.9141	0.0057	0.5685
7	0.0047	20.1716	0.4682	19.7424	0.0005	0.0684
F	0.0046	19.7424				
Total	0.0233					

ANDERSEN IMPACTOR

Date 11/18/75 Run # 2122

Sample volume at STP (ft^3) = 6.8863

Moisture (%) = 0.9866

Concentration (grains/ft^3) = 0.09791

Impactor flow rate (acfm) = 0.4591

Location Inlet

Orifice

Bar. press. ("Hg) = 30.21
Mw = 29
Avg. Pm (-"Hg) = 2.23
Avg. Tm ($^\circ$F) = 73
H_2O (grams or %) = 1.32
Meter volume (ft^3) = 7.34
Avg. Ps ($\pm H_2O$) = - 0.48
Avg. Ts ($^\circ$F) = 75
Time (minutes) = 15
Correction factor = 1

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% ≤ stated size	dm/d log D	Geo. Mean (μm)
Probe & expander	0.0037	8.55		91.46		
0	0.0010	2.31	14.1685	89.146	0.0078	11.2012
1	0.0007	1.62	8.8553	87.529	0.0092	7.2585
2	0.0007	1.62	5.9497	85.912	0.0142	4.9542
3	0.0010	2.31	4.1254	83.603	0.0218	3.2502
4	0.0020	4.62	2.5607	78.984	0.0754	1.8515
5	0.0094	21.71	1.3386	57.275	0.1235	1.0483
6	0.0116	26.79	0.8209	30.485	0.1486	0.6802
7	0.0108	24.94	0.5637	5.543	0.0031	0.0750
F	0.0024	5.543				
Total	0.0433					

ANDERSEN IMPACTOR

Date 11/18/75 Run # 2122

Sample volume at STP (ft^3) = 80.2753

Moisture (%) = 0.9132

Concentration ($grains/ft^3$) = 0.0106

Impactor flow rate (acfm) = 0.6773

Location Outlet

Orifice

Bar. press. ("Hg) = 30.21
Mw = 28.7
Avg. Pm (-"Hg) = 2.9
Avg. Tm (°F) = 76
H_2O (grams or %) = 15.5
Meter volume (ft^3) = 88.15
Avg. Ps ($\pm H_2O$) = 1.02
Avg. Ts (°F) = 81
Time (minutes) = 120
Correction factor = 1

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% ≤ stated size	dm/d log D	Geo. Mean (μm)
Probe & expander	0.0005	0.9140		90.0850		
0	0.0003	0.5484	11.6645	98.5374	0.0008	9.2216
1	0.0009	1.6453	7.2903	96.8921	0.0014	5.9641
2	0.0013	2.3766	4.8792	94.5155	0.0024	4.0652
3	0.0020	3.6536	3.3870	90.8592	0.0026	2.6779
4	0.0028	5.1188	2.1172	85.7404	0.0072	1.5245
5	0.0107	19.5612	1.0978	66.1791	0.0155	0.8550
6	0.0174	31.8098	0.6659	34.3692	0.0147	0.5477
7	0.0129	23.5831	0.4505	10.7861	0.0006	0.0671
F	0.0059	10.7861				
Total	0.0547					

ANDERSEN IMPACTOR

Date 12/5/75 Run # 1122

Sample volume at STP (ft^3) = 9.0883

Moisture (%) = 0.8327

Concentration (grains/ft^3) = 0.0877

Impactor flow rate (acfm) = 0.6062

Location Inlet

Orifice E

Bar. press. ("Hg) = 30.39
Mw = 29
Avg. Pm (-"Hg) = 2.2
Avg. Tm (^{o}F) = 74
H_2O (grams or %) = 1.6
Meter volume (ft^3) = 9.64
Avg. Ps ($\pm H_2O$) = -0.06
Avg. Ts (^{o}F) = 79
Time (minutes) = 15
Correction factor = 1

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% ≤ stated size	dm/d log D	Geo. Mean (μm)
Probe & expander	0.0042	8.2031		91.7969		
0	0.0015	2.9297	12.3304	88.8672	0.0034	9.7480
1	0.0004	0.7813	7.7065	88.0859	0.0059	6.3081
2	0.0006	1.1719	5.1634	86.9141	0.0151	4.3014
3	0.0014	2.7344	3.5832	84.1797	0.0309	2.8302
4	0.0037	7.2266	2.2354	76.9531	0.0801	1.6115
5	0.0133	25.9766	1.1618	50.9766	0.1365	0.9062
6	0.0172	33.5928	0.7069	17.3828	0.0785	0.5827
7	0.0077	15.0391	0.4803	2.3438	0.0012	0.0693
F	0.0012	2.3438				
Total	0.0512					

ANDERSEN IMPACTOR

Date 12/5/75 Run # 1122

Sample volume at STP (ft^3) = 37.6762

Moisture (%) = 2.1342

Concentration (grains/ft^3) = 0.0127

Impactor flow rate (acfm) = 0.6333

Location Outlet

Orifice D

Bar. press. ("Hg) = 30.39

Mw = 28.7

Avg. Pm (-"Hg) = 2.25

Avg. Tm (°F) = 75.5

H_2O (grams or %) = 17

Meter volume (ft^3) = 39.52

Avg. Ps ($\pm H_2O$) = 0.36

Avg. Ts (°F) = 83

Time (minutes) = 60

Correction factor = 1

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% ≤ stated size	dm/d log D	Geo. Mean (μm)
Probe & expander	0.0012	3.9604		96.0396		
0	0.0001	0.3300	12.0629	95.7096	0.0006	9.5365
1	0.0003	0.9901	7.5393	94.7195	0.0014	6.1699
2	0.0006	1.9802	5.0492	92.7393	0.0024	4.2065
3	0.0009	2.9703	3.5044	89.7690	0.0023	2.7690
4	0.0011	3.6304	2.1879	86.1386	0.0065	1.5766
5	0.0044	14.5215	1.1361	71.6172	0.0168	0.8856
6	0.0087	28.7129	0.6904	42.9043	0.0248	0.5686
7	0.0100	33.0033	0.4683	9.9010	0.0008	0.0684
F	0.0030	9.9010				
Total	0.0303					

ANDERSEN IMPACTOR

Date 11/17/75 Run # (2322)

Sample volume at STP (ft^3) = 7.2045

Moisture (%) = 1.0505

Concentration (grains/ft^3) = 0.1359

Impactor flow rate (acfm) = 0.4818

Location Inlet

Orifice E

Bar. press. ("Hg) = 30.16

Mw = 29

Avg. Pm (-"Hg) = 1.5

Avg. Tm (°F) = 74

H_2O (grams or %) = 1.6

Meter volume (ft^3) = 7.5

Avg. Ps (±H_2O) = - 0.3

Avg. Ts (°F) = 76

Time (minutes) = 15

Correction factor = 1

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% ≤ stated size	dm/d log D	Geo. Mean (μm)
Probe & expander	0.0037	5.8917		94.1083		
0	0.0019	3.0255	13.8309	91.0828	0.0085	10.9343
1	0.0008	1.2739	8.6443	89.8089	0.0125	7.0839
2	0.0010	1.5924	5.8051	88.2166	0.0177	4.8342
3	0.0013	2.0701	4.0257	86.1465	0.0283	3.1731
4	0.0027	4.2994	2.5011	81.8471	0.0821	1.8074
5	0.0107	17.0382	1.3062	64.8089	0.1840	1.0221
6	0.0181	28.8217	0.7999	35.9873	0.2138	0.6622
7	0.0162	75.7962	0.5483	10.1911	0.0080	0.0740
F	0.0054	10.1911				
Total	0.0628					

ANDERSEN IMPACTOR

Date 11/17/75 Run # (2322)
Sample volume at STP (ft^3) = 65.1860
Moisture (%) = 0.8345
Concentration (grains/ft^3) = 0.0038
Impactor flow rate (acfm) = 0.5428

Location Outlet
Orifice D
Bar. press. ("Hg) = 30.16
Mw = 28.7
Avg. Pm (-"Hg) = 1.9
Avg. Tm (°F) = 75
H_2O (grams or %) = 11.5
Meter volume (ft^3) = 69.10
Avg. Ps ($\pm H_2O$) = 0.3
Avg. Ts (°F) = 74
Time (minutes) =120
Correction factor = 1

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% ≤ stated size	dm/d log D	Geo. Mean (μm)
Probe & expander	0.0005	3.1250		96.8750		
0	0.0003	1.8750	13.0296	95.0000	0.0004	10.3008
1	0.0003	1.8750	8.1435	93.1250	0.0007	6.6695
2	0.0005	3.1250	5.4623	90.0000	0.0000	4.5495
3	0.0000	0.0000	3.7893	90.0000	0.0010	2.9900
4	0.0009	5.6250	2.3593	84.3750	0.0023	1.7028
5	0.0027	16.8750	1.2290	67.5000	0.0059	0.9602
6	0.0053	33.1250	0.7501	34.3750	0.0033	0.6196
7	0.0023	14.3750	0.5118	20.0000	0.0004	0.0715
F	0.0032	20.0000				
Total	0.0160					

ANDERSEN IMPACTOR

Date 12/13/76 Run # Metal Foam #1
Sample volume at STP (ft^3) = 7.721717
Moisture (%) = 0.918837
Concentration (grains/ft^3) = 0.093176
Impactor flow rate (acfm) = 0.510891

Location Inlet
Orifice E
Bar. press. ("Hg) = 30.38
Mw = 29
Avg. Pm (-"Hg) = 2.13
Avg. Tm (°F) = 72.3
H_2O (grams or %) = 1.5
Meter volume (ft^3) = 8.14
Avg. Ps ($\pm H_2O$) = -0.45
Avg. Ts (°F) = 74°F
Time (minutes) = 15
Correction factor = 1

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% ≤ stated size	dm/d log D	Geo. Mean (μm)
Probe & expander	0.0046	12.234		87.766		
0	0.0011	2.926	13.431	84.840	0.00395	10.6181
1	0.0004	1.064	8.394	83.777	0.01165	6.8770
2	0.0010	2.660	5.634	81.117	0.02285	4.69210
3	0.0018	4.787	3.908	76.330	0.03422	3.08172
4	0.0035	9.309	2.430	67.021	0.08776	1.7552
5	0.0037	9.840	1.268	57.181	0.13874	0.99118
6	0.0147	39.096	0.775	18.085	0.07578	0.64093
7	0.0062	16.489	0.530	1.596	0.00070	0.073
F	0.0006	1.596				
Total	0.04620					

ANDERSEN IMPACTOR

Date 1/13/76   Run # Metal Foam #1   Location Outlet

Sample volume at STP (ft^3) = 75.041321
Moisture (%) = 1.040027
Concentration (grains/ft^3) = 0.009101
Impactor flow rate (acfm) = 0.62204

Orifice D
Bar. press. ("Hg) = 30.38
Mw = 28.7
Avg. Pm (-"Hg) = 2.72
Avg. Tm (°F) = 72.4
H_2O (grams or %) = 16.5g
Meter volume (ft^3) = 80.71
Avg. Ps (±H_2O) = +0.92
Avg. Ts (°F) = 77
Time (minutes) = 120
Correction factor = 1

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% ≤ stated size	dm/d log D	Geo. Mean (μm)
Probe & expander	0.0024	5.48		94.52		
0	0.0003	0.68	12.17	93.84	0.00031	9.6228
1	0.0003	0.68	7.61	93.15	0.00096	6.2263
2	0.0008	1.83	5.10	91.32	0.00105	4.2452
3	0.0008	1.83	3.54	89.50	0.00274	2.7940
4	0.0027	6.16	2.21	83.33	0.00570	1.59085
5	0.0078	17.81	1.15	65.53	0.01327	0.89404
6	0.0138	31.51	0.697	34.02	0.01260	0.574
7	0.0102	23.29	0.473	10.73	0.00058	0.069
F	0.0047	10.73				
Total	0.0438					

ANDERSEN IMPACTOR

Date 1/13/76 Run # Metal Foam #2

Sample volume at STP (ft^3) = 7.726561

Moisture (%) = 0.918261

Concentration (grains/ft^3) = 0.109241

Impactor flow rate (acfm) = 0.511212

Location Inlet

Orifice E

Bar. press. ("Hg) = 30.38
Mw = 29
Avg. Pm (-"Hg) = 1.9
Avg. Tm (°F) = 73°
H_2O (grams or %) = 1.5
Meter volume (ft^3) = 8.09
Avg. Ps ($\pm H_2O$) = -0.45
Avg. Ts (°F) = 74
Time (minutes) = 15
Correction factor = 1

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% ≤ stated size	dm/d log D	Geo. Mean (μm)
Probe & expander	0.0051	9.41		90.59		
0	0.0009	1.66	13.427	88.93	0.00889	10.615
1	0.0009	1.66	8.39	87.27	0.01164	6.875
2	0.0010	1.85	5.63	85.42	0.203	4.691
3	0.0016	2.95	3.91	82.47	0.0420	3.081
4	0.0043	7.93	2.43	74.54	0.0963	1.755
5	0.0135	24.91	1.27	49.63	0.16223	0.991
6	0.0172	31.73	0.775	17.90	0.10138	0.641
7	0.0083	15.31	0.530	2.58	0.00164	0.073
F	0.0014	2.58				
Total	0.0542					

ANDERSEN IMPACTOR

Date 1/13/76 Run # Metal Foam # 2 Location Outlet

Sample volume at STP (ft^3) = 38.606736
Moisture (%) = 1.163916
Concentration (grains/ft^3) = 0.008249
Impactor flow rate (acfm) = 0.640046

Orifice D
Bar. press. ("Hg) = 30.38
Mw = 28.7
Avg. Pm (-"Hg) = 2.26
Avg. Tm (°F) = 73.8
H_2O (grams or %) = 9.52
Meter volume (ft^3) = 40.9
Avg. Ps ($\pm H_2O$) = 0.92
Avg. Ts (°F) = 77
Time (minutes) = 60
Correction factor = 1

Stage	Net weight (gm)	% on stage	Size cutoff (μm)	% ≤ stated size	dm/d log D	Geo. Mean (μm)
Probe & expander	0.0015	7.35		92.65		
0	0.0000	0	12.00	92.65	0.00020	9.486
1	0.0001	0.49	7.50	92.16	0.00116	6.137
2	0.0005	2.45	5.02	89.71	0.00128	4.184
3	0.0005	2.45	3.49	87.25	0.00218	2.755
4	0.0011	5.39	2.18	81.86	0.00767	1.568
5	0.0054	26.47	1.13	55.39	0.0157	0.881
6	0.0084	41.18	0.687	14.22	0.00407	0.565
7	0.0047	8.33	0.466	5.88	0.00029	0.068
F	0.0012	5.88				
Total	0.0204					

APPENDIX D

OPTICAL PARTICLE COUNTER MEASUREMENTS AND DATA

GCA/Technology Division utilizes a Bausch and Lomb Dust Counter Model 40-1 which is capable of optically counting dust particles at particle sizes equal to or greater than 0.3 μm, 0.5 μm, 1.0 μm, 2.0 μm, 3.0 μm, 5.0 μm, and 10.0 μm. The dust counter was used in conjunction with the dilution systems mentioned for use with the CNC.

Readings were taken at 0.3 μm and were often high enough to be very close to the maximum counting capabilities of the instrument. Readings at 0.5 μm and 1.0 μm were normally well within the counting range of the instrument while readings at 2 μm and higher were often very low or zero. Therefore, the data were considered valid only for the 0.3 μm, 0.5 μm, 1.0 μm, and 2.0 μm settings. Table 13 contains the data obtained with the optical particle counter.

Table 13. OPTICAL PARTICLE COUNTER DATA

	Particle diameter	Concentration
Run no.	Lower limit, µm	Number of particles per 0.01 ft^3
3222 Inlet	0.3	3.19×10^6
	0.5	1.34×10^6
	1.0	5.83×10^5
	2.0	4530
Outlet	0.3	1.15×10^6
	0.5	3.18×10^4
	1.0	1.28×10^4
	2.0	637
1222 Inlet	0.3	1.67×10^6
	0.5	2.58×10^5
	1.0	6.92×10^4
	2.0	31
Outlet	0.3	7.90×10^5
	0.5	1.31×10^4
	1.0	3887
	2.0	0
3122 Inlet	0.3	3.50×10^6
	0.5	1.12×10^6
	1.0	5.04×10^5
	2.0	3.74×10^4
	3.0	2770
	5.0	1517

Table 13 (continued). OPTICAL PARTICLE COUNTER DATA

Run no.	Particle diameter Lower limit, μm	Concentration Number of particles per 0.01 ft^3
Outlet	0.3	1.57×10^5
	0.5	6.53×10^4
	1.0	2.88×10^4
	2.0	85.5
	3.0	8.1
	5.0	0
1122 Inlet	0.3	1.67×10^6
	0.5	2.58×10^5
	1.0	6.92×10^4
	2.0	31
Outlet	0.3	7.1×10^5
	0.5	7910
	1.0	2336
	2.0	53

APPENDIX E

CONDENSATION NUCLEI COUNTER MEASUREMENTS AND DATA

GCA/Technology Division utilizes a Rich Model 100 Condensation Nuclei Counter (CNC) in conjunction with the Diffusion Denuder (DD) for submicrometer particle sizing measurements. The efficiency of particle removal by the DD is a function of flow rate through the device, as shown in Figure 28, so that the utilization of different flow rates will allow size distribution measurements with the CNC.

To obtain successful measurements with the CNC it is often necessary to dilute and modify the static pressure of the gas stream to be sampled. Various diluters are employed by GCA/Technology Division. Each system mixes the sample stream with filtered air, and the measured flow rates of the sample and dilution streams are used to calculate the total sample dilution.

Dilution systems were utilized to dilute the gas stream up to 200 times and to raise the static pressure of the gas stream, since the CNC will not operate properly if the static pressure of the sample is too far below atmospheric.

Table 14 contains the data obtained with the CNC.

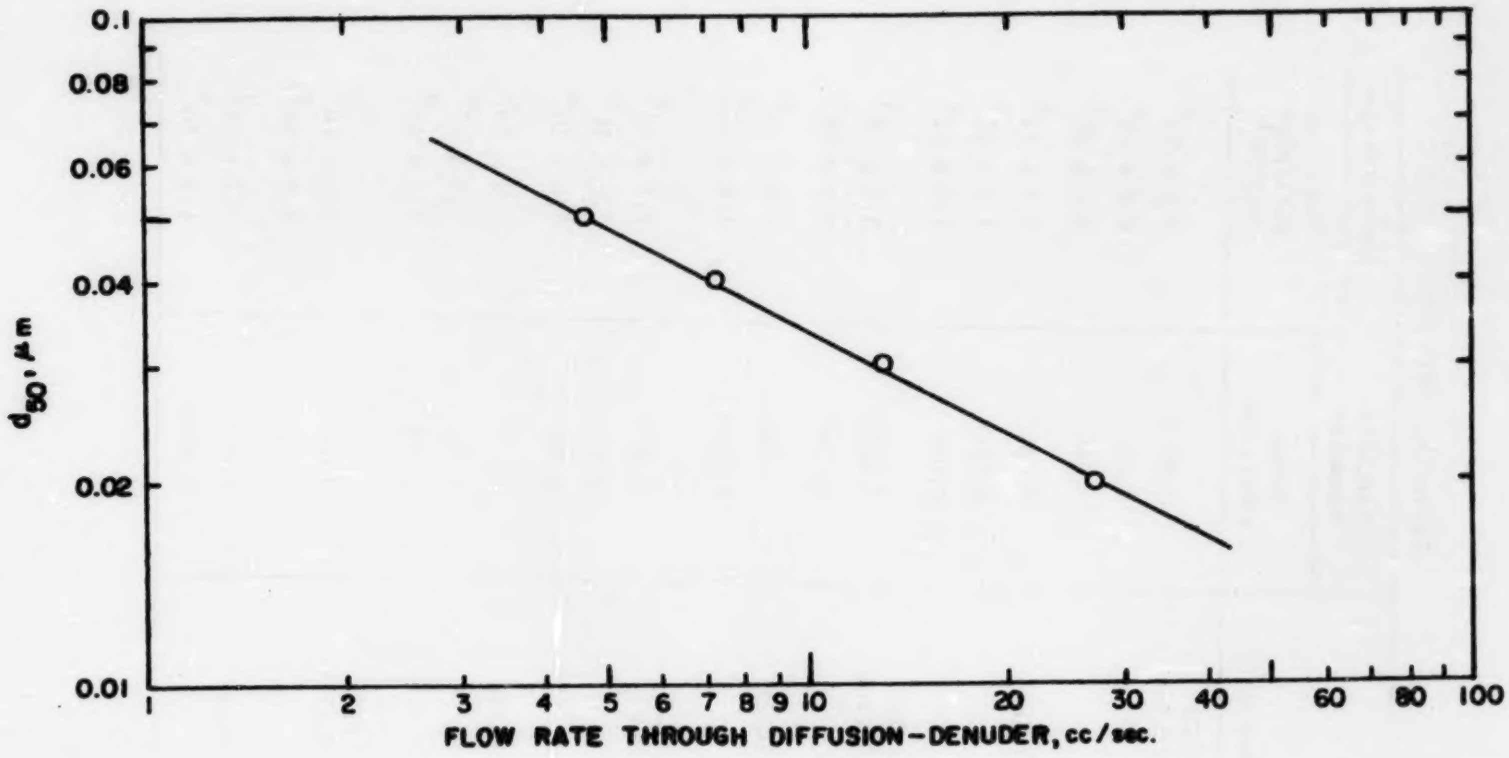

Figure 28. Diffusion denuder size cutoffs as a function of flow rate

Table 14. CNC DATA

	Particle diameter	Concentration
Run no.	Lower limit, µm	Number of particles per cm^3
3222 Outlet	0.0025	3.1×10^6
	0.0145	2.8×10^6
	0.048	6.4×10^5
Inlet	0.0025	3.8×10^6
	0.0145	3.6×10^6
	0.048	8.4×10^5
1222 Outlet	0.0025	5.3×10^6
	0.0145	7.7×10^5
Inlet	0.0025	2.2×10^6
	0.0145	1.4×10^6
3122 Outlet	0.0025	2.6×10^6
	0.0145	2.1×10^6
	0.048	5.8×10^5
Inlet	0.0025	2.8×10^6
	0.0145	3.0×10^6
	0.048	1.1×10^6
1122 Outlet	0.0025	3.9×10^6
	0.0145	9.2×10^5
Inlet	0.0025	2.2×10^6
	0.0145	1.4×10^6